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Vol. X, No. 40

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THE ADVANCEMENT OF SCIENCE

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THE SCIENTIFIC BIAS OF ARCHAEOLOGY[1]

by

W. F. GRIMES

My title is the scientific bias of archaeology : I ignore for the moment its question-begging quality and assume that what is wanted from me is not a straightforward account of the uses which archaeology makes of evidence obtained from 'scientific' subjects, but a statement of the archaeological approach to archaeological problems : the view from within, as it were, of aims and objectives, the attitude towards evidence and the use made of it, however obtained.

I must not weary you with definitions of archaeology beyond reminding you that in essence it is less a subject in its own right than a method : a method of elucidating history and human geography in the ages before written record ; of enlarging and extending our knowledge of human culture when written records have become the chief source of information. In any discussion of scientific bias it is therefore impossible not to take at least a passing glance at the long-standing problem of history as art or science ; and to analyse briefly the inter-relationships of the two. The same question does not present itself in the case of geography, whose practitioners, as far as my admittedly limited knowledge goes, have not in any number claimed status for their discipline as an art.

The crucial test in a matter of this sort I take to be the attitude towards evidence. Archaeology is a young discipline, still in many respects feeling its way towards more perfect techniques in the amassing and interpretation of its evidence. Even now it is not entirely weaned from the outlook of the pioneers whose 'collector-mentality' led them to value antiquities more for their intrinsic worth than for their significance as evidence ; and who from a literary background often sought fantastic and romantic explanations for both sites and objects. It is not surprising then that archaeology has been the victim of a certain degree of mistrust from two sides, from scientists and historians alike.

The former I leave for the moment. Amongst the historians there are welcome signs that the attitude to archaeological method has changed, though in places criticism still persists. It springs, I take it, from the fact that the contemporary or near-contemporary statements which are the raw material of history in the narrower sense have a precision which is lacking in the potsherds and other things which comprise archaeological evidence. To one accustomed to working with documents conclusions based upon such mute objects may well appear to be too subjective to be of value ; but views of this sort are too often the result of failure to grasp the basic principles of modern archaeological practice or to understand what archaeologists expect or hope to do.

I do not think that what I have just said exaggerates the position with regard to a number (I think a dwindling number) of historians. It would not of course be difficult to demonstrate that 'historical' evidence in the narrower sense can in some of its forms possess an unreliability which may be lacking in the more material evidence of the archaeologists. The contemporary statements of writers can be—and often are—affected by inborn inaccuracy or carelessness or by some obscure *arrière-pensée* ; the pots and pans of archaeology on the other hand are the outcome of human activity which reflects events and processes in an entirely unselfconscious and thus unbiased way.

In reminding you of this I am not of course suggesting that archaeological evidence is superior to 'historical' evidence : such a position would clearly be untenable. I merely wish to emphasise that where the two disagree on a given point it will not necessarily be an act of wisdom to dismiss the archaeological out of hand as being the more unreliable. For the rest, the

[1] Paper delivered to the Assembly of Corresponding Societies at Liverpool on September 4, 1953.

central aim of all historical research is the elucidation of human ideas and institutions. 'Historical' evidence, like all evidence to do with the past, is incomplete; but being the more or less direct expression of the human mind is the more sensitive instrument with which 'art,' intuitive insight, understanding and interpretation, call it what you will, have the greatest play. The raw material of archaeology, on the other hand, is even more patently incomplete within its own already narrow material limits. It is as a general rule confined to imperishable objects: and on the rare occasions when favourable conditions allow the survival of organic substances, for instance, it comes as something of a shock to realise how much has been lost to the processes of time.

The historian is therefore at the inestimable advantage that having satisfied himself on his evidence he can bring his 'art' to bear upon his subject's intellectual activities as well as upon the interpretation of character, the interplay of personalities and the rest. The archaeologist may achieve a partial view of the material and economic life of pre- or proto-historic man—in many important aspects he adds considerably to knowledge of historic man also—but outside these comparatively limited fields his knowledge is largely by implication. For artistic tendencies he is restricted to an expression which often is at once primitive, applied and conditioned by technological progress or the lack of it; for social customs and religious ideas he must work from burial-monuments and dwelling-sites which may also contribute something to a knowledge of political organisation. Such sources he can at times augment (with due caution) by analogy with the thought and practice of modern primitive peoples at a comparable stage of development.

Here, obviously, there is scope—many would think dangerous scope—for subjective speculation. The truth of course is that both 'history' and archaeology must be scientific in the respect that they show for, and the use they make of, their evidence. I hope it is not over-simplifying the matter to suggest that the difference lies largely in the quality of that evidence, with the historical affording greater insight into the human mind and its operation; the archaeological essentially material and dependent for its understanding upon scientific and technical processes.

We are then at this stage face to face with the scientific bias which my title postulates. Whatever the conclusions to be drawn from archaeological evidence, the appreciation of that evidence is a scientific matter. The products of man which form the main bulk of archaeological raw material are material things: some specialised scientific and technological knowledge is essential to an understanding of them. The technology of stone and metal implements demands a smattering of petrological, geological and metallurgical information; the position is the same with the domestic crafts. The phases in the endless fight between man and his environment—one of the main themes of modern archaeological research in this country—demand a grasp, specialised again, of certain aspects of the natural sciences. Your archaeologist cannot record a field-monument without recalling at least the elements of the geometry that he probably discarded in his school days; nor can he excavate his monument efficiently without an intelligent eye on its geological characters.

I shall perhaps be accused of putting the cart before the horse in discussing the archaeologist's general handling of his evidence before considering the scientific validity of the evidence itself. We have seen that that evidence is limited both in range and in expression. There are many aspects of early life which persist unillumined by the imperishable forms of material equipment even in the business of day-to-day living. The mental processes of early man remain almost entirely a matter of inference. But no one who will devote any time to the matter can fail to be impressed by the fact that the raw material of archaeological research is capable of—and actually receives—scientific treatment.

In any discussion of archaeological beginnings one ought perhaps to distinguish between the early antiquarians and the early archaeologists, though the dividing line between the two is not always clear. The antiquarians were essentially book-learned: their view of monuments was always clouded by their knowledge

of classical or barbarian history or myth, which they used as the basis for theories developed within the four walls of their studies. The early archaeologists on the other hand, with whom the future really lay, started out as collectors, with their eye mainly on good specimens worthy of their cabinets : as I have said, they valued objects for their intrinsic qualities rather than for the evidence that they might yield about contemporary man.

The preoccupation with ' the specimen ' led naturally to the production of ' typological ' studies whose value lay in the fact that they created a workable system of sequences to form the basis of a relative if not of an absolute chronological scheme. The basic principles of typology are sound enough : they can be seen in operation as well in the bonnet of a modern motor-car as in an axe of the Bronze Age. But if typology for its own sake is now a less favourite pursuit than it was, that is because it tells only a part of the story. All human products are expressions of culture, though some may be more specialised than others : modern archaeology recognises that they will only be properly understood if the technological changes which they embody are seen against the cultural background, which in this case involves amongst other things the study of associations and of distribution. The coherence of the system that is being created, supported as it frequently is from non-archaeological sources, is itself evidence of its soundness. This sociological approach sees the thing whole, recognises that its objective is Man and values his products at least as much as means to an end as for their intrinsic interest as either rare or beautiful things.

Merely *because* it ' sees the thing whole ' archaeology cannot rule out the aesthetic view, for all its subjectivity, though it is a little disquieting to observe in some archaeological museums a tendency to emphasise aestheticism : their collections are displayed as if they were composed of art rather than of archaeological objects. Nevertheless, nowhere is the developing attitude of modern archaeology more significantly shown than in the readiness to apply scientific techniques to antiquities as a method of drawing further knowledge from them, even when such techniques involve destruction or defacement of the object itself. I doubt whether twenty years ago it would have been possible to launch a national project for identifying petrologically the sources of stone implements, since the essence of the technique is the mutilation of the implement to obtain the necessary microscopic section for petrological study. The survey is now a going concern for three reasons : change of heart on the part of archaeologists and museum curators ; the devising by the petrologists of a method of cutting and healing which does minimum damage to the specimen—and the valuable results obtained from the method by a pioneer group of workers in the west of England.

There, I suggest, we can appropriately leave this part of our subject with the principle well on the way to acceptance that antiquities are the raw material for research whose physical sanctity may have to be sacrificed in the interests of the truth. There are, however, two qualifications to this. First the outstanding quality or the uniqueness of certain objects may be such that no interference with them would be justified. Secondly, whereas much of the raw material of the natural sciences is to all intents and purposes endlessly repetitive and therefore expendable, the stock of archaeological evidence will always be limited : its preservation as unimpaired as possible is therefore important. But this is probably merely a passing difficulty, with the development of such techniques as micro-chemical tests which achieve their results with little or no damage to the specimen.

New as the principle may be said to be for movable antiquities, it had perforce to be accepted in the excavation of field monuments. Excavation must mean mutilation and destruction ; and such destruction, in the case of such monuments as Bronze Age barrows, is final. Here, too, a modern sense of responsibility demands the restoration of the site as completely as possible to its original condition, so that it remains as a visible record of the past with its internal features preserved.

The development of excavation technique follows lines parallel with those for the study of movable objects. Early excavators ' hogged ' barrows with an eye simply to their yield in terms of finds ;

yet from quite an early stage the best of them left some account of the features which they encountered in the mounds themselves and their records provide us with the burial-groups which are an essential element in the formulation of both typological sequences and cultural patterns, especially in the early part of the Bronze Age. Again, the need to see the thing whole increasingly made itself felt : the history of barrow excavation has been the development of more methodical techniques aimed at the structure of the monument as much as its burials, with an ever-increasing awareness of the value of the results as pointers to ritual and religious practices centred upon the dead, and therefore as ways to an understanding of an important part of the mind of primitive man. It will be readily conceded that interpretation here presents ample opportunity for the exercise of the imagination. But there can be no harm in that provided that there is no confusion between ascertained fact and theory.

The development of scientific technique in excavation is, however, best illustrated by its application to occupation sites, in which Pitt-Rivers was the pioneer. Here again the cardinal principle is that 'finds' are important in terms of the conditions in which they are found. The essence of the matter is the isolation of individual structures, hut sites and the like, vertically so that the succession of events can be established on the principles of stratigraphy which have been long accepted by geologists ; horizontally so that distribution and density may be estimated in terms of a plan. The associated finds serve not merely to date structures but to establish their cultural context and their economic and social setting ; and the collaboration of natural scientists of various branches may add information on environment and contemporary natural conditions which may have a value for other studies. Archaeological excavation as practised under modern conditions has a method and a flexibility which can be claimed to be truly scientific : it works according to clearly defined principles and its best practitioners bring to their task an imaginative awareness not merely of their own problems but of the contribution which they may make to the problems of others in ecology and the like.

This brings me to the last part of my subject : the relationship of archaeology with the sciences. Implicit in much of what I have said there is, I hope, a recognition of the contribution which the older sciences make to archaeological progress, whether it be in the handling of archaeological material or in environmental problems and the like. Here scientists have been critical of archaeologists in the past, and I think not without reason. For it is not difficult to detect weaknesses in the archaeologist's attitude : a too-ready assumption that science exists to serve as a sort of technical assistant to archaeology ; a tendency to come to facile conclusions on scientific matters with an inadequate background of knowledge in the subject ; even, at times, a habit of seeking scientific help while not observing scientific rules and requirements—as in the provision of suitable samples for examination.

Such troubles will no doubt resolve themselves with time : the teaching institutions are now seeking to redress the balance. The requirement seems to be specialised training aimed not to give the archaeologist a dangerous smattering in the sciences but to make him aware of his own ignorance and equip him to see the scientific possibilities of an archaeological situation so that he can help his scientific colleagues to make the fullest use of it.

For obviously it is useless to think of converting the archaeologist into a scientist in the narrower sense. His main preliminary training is usually in the humanities—and rightly so ; and his mind and hands are already full. I would much prefer to see more scientists applying themselves to archaeology—as a number already do to the outstanding benefit of us all. And this, I hasten to add, should not be taken as yet another piece of archaeological condescension. Nowhere is it more true that all knowledge is one : I believe that in this context scientists—including archaeologists—should regard early man as yet another animal, though with a more profound influence than most upon the world of nature. Taking this view they will find that archaeology has its own contribution to make to their understanding of the world in which we live.

THE JOURNEY TO WORK ON MERSEYSIDE

In Section E on Thursday, September 3, 1953, three papers were read relating to an enquiry on the Journey to Work on Merseyside being carried out in the Liverpool Department of Geography by Prof. Wilfred Smith, Mr. K. Rowe and Mr. G. Mercer. The paper printed below is that by Mr. K. Rowe on Isochrone Maps and the Journey to Work.

Isochrone Maps and the Journey to Work

by

K. Rowe

In the course of the investigation into the Journey to Work particulars of residence were collected for some 40,000 employees of Merseyside firms. These specific residences have been mapped in relation to specific workplaces. A series of isochrone maps has also been drawn, each based on calculated time of journey to a specific workplace, in order to discover whether it is possible to define under what conditions length of journey in terms of time is significant in the relationship between workplace and residence. The time-zones in the isochrone maps are calculated from a specific point, each within a different industrial or commercial area of Merseyside. In some cases, this specific point is the site of a firm from which details of employees' residences have been collected : in other cases, the site of the firm is close at hand. It is hoped to show in this paper the value and limitation of isochrone maps for this purpose.

The sources of the data from which the isochrone maps were drawn are the passenger transport time-tables issued by the several Merseyside Corporations, the British Railways and those bus companies (Ribble and Crosville), which are independent of local authorities. It is based not on a single means of transport, as are so many previous isochrone maps, but on all public transport. Before the maps could be compiled, several simplifying assumptions relating to the journey to work had to be made. In the first place, it was assumed that the quickest route to work is used, regardless of cost, except that express trains not stopping between the Liverpool terminus and towns marginal to the Merseyside District (e.g. Wigan, Earlestown) were omitted. Inclusion of such express services in the computations would extend and partly obscure the pattern of isochrones within the conurbation ; moreover, very few employees of firms visited live in towns served by such express trains. Secondly, it was assumed that the times of peak-hour week-day services would represent adequately the conditions of the daily journey to work. No waiting time was allowed when connections between different services would have to be made. It is a not unreasonable assumption that those travelling daily would organise their journey efficiently. From the workplace, and from any railway station or bus stop the completion of the journey by walking (at a speed of 3 mp.h.) was taken into account. Isochrones were then drawn at time intervals of 10 minutes, the bounding isochrone being that of 1 hour from the central point. The isochrone map is intended to give, therefore, a picture of the time taken on the journey to a selected point from all parts of Merseyside, under strictly defined conditions.

Several limitations to the use of isochrone maps constructed on this basis immediately present themselves. The times calculated are necessarily ' theoretical,' taking no account of personal reasons (such as health, convenience for shopping, etc.) for choosing a particular route or means of transport. Further, the method omits the possibility of travel by longer, slower routes which are used on account of their cheapness. The actual time taken

in getting to work will therefore, in many cases, be greater than that shown on the isochrone map. Also the map places undue emphasis on the part played by railways in the journey to work ; bus services are slower but cheaper. It is evident that no account can be taken of travel by means other than public transport services. Few employees use cars for the journey to work, but a considerable number of workers at some firms visited use the bicycle as their means of transport. No account, moreover, is taken of the frequency of the various transport services. It is, in fact, assumed that connections are immediately obtainable. The fact that peak-hour services are usually frequent does often ensure a minimum of waiting time. It should be pointed out that the maps were drawn from data valid in the winter of 1951. Since that time, alteration of some railway services and the conversion of some tram routes into bus routes have changed the isochrone pattern in details.

The isochrone map centred on Liverpool Town Hall (Fig. 1) is equally valid for the numerous business firms clustered in the city area. With good railway services available from the three main stations, the 60-minute isochrone extends far beyond the Liverpool boundary, to beyond Southport, Wigan, St. Helens and Runcorn. That the north has more rapid access to the city centre is due to the proximity of Exchange Station with its electric train services to Southport and Ormskirk. The northern part of the Wirral peninsula is also well served by other electric trains from the city. It was the provision of a rapid train service to Liverpool that stimulated the growth of residential areas across the Mersey, e.g. West Kirby. Though both Birkenhead and Wallasey are served by ferries from Pier Head, of the two towns Birkenhead is more rapidly accessible from the city, owing to the route of the Mersey railway passing through Birkenhead before sending a branch line to Wallasey.

From the distribution of employees' residences for Firm A, which employs primarily clerical labour (Fig. 2), the importance of the trans-Mersey movement to work can be inferred. Forty per cent. of the employees live in Wirral. According to the isochrone map compiled from Liverpool Town Hall, which adjoins Firm A, one-half of the employees travel between 20 and 30 minutes to work ; Wallasey, outer Birkenhead, Crosby and the ring of better Liverpool suburbs with a fairly low housing density fall within this time zone. On the other hand, few employees live in the more densely built-up parts of Bootle, which also can be reached in between 20 and 30 minutes. Of the persons travelling for less than 20 minutes to work, the great majority also lives in areas with lower housing densities. The city area is almost devoid of residences ; under 1 per cent. of Firm A's employees have a journey of less than 10 minutes. The employees who travel for between 30 and 40 minutes to work make up one-fifth of the total, and most of them live in western Wirral, south Liverpool and Formby, all of which have a great attraction for salaried workers. The proportion of employees having over an hour's journey to work is negligible, as in all succeeding examples.

The isochrone map included as Fig. 3 is centred upon part of the Edge Lane industrial zone of east Liverpool. Owing to the proximity of the area to those passenger transport routes which trend eastwards and south-eastwards from the city centre, the isochrones are extended in these directions. The towns north and west of Liverpool are reached less rapidly. St. Helens, Widnes and Runcorn are well within an hour's travelling time of the Edge Lane district.

Firm B is a manufacturing firm upon which the previous isochrone map is centred and for which a 25 per cent. sample of the residences of female employees has been plotted, in Fig. 4. It is poorly served by passenger transport routes. Analysis reveals that, with one exception, the factory can be reached within 30 minutes by every employee. One-fifth of its employees live within 10 minutes' travelling distance ; the rest are equally divided between the time zones of 20 to 30 and 10 to 20 minutes. It is almost certain that buses or trams are the only means of public transport used for the journey to work in this example. The Edge Lane industrial zone is surrounded by a belt of residential areas which supply

FIGURE 1

FIGURE 2

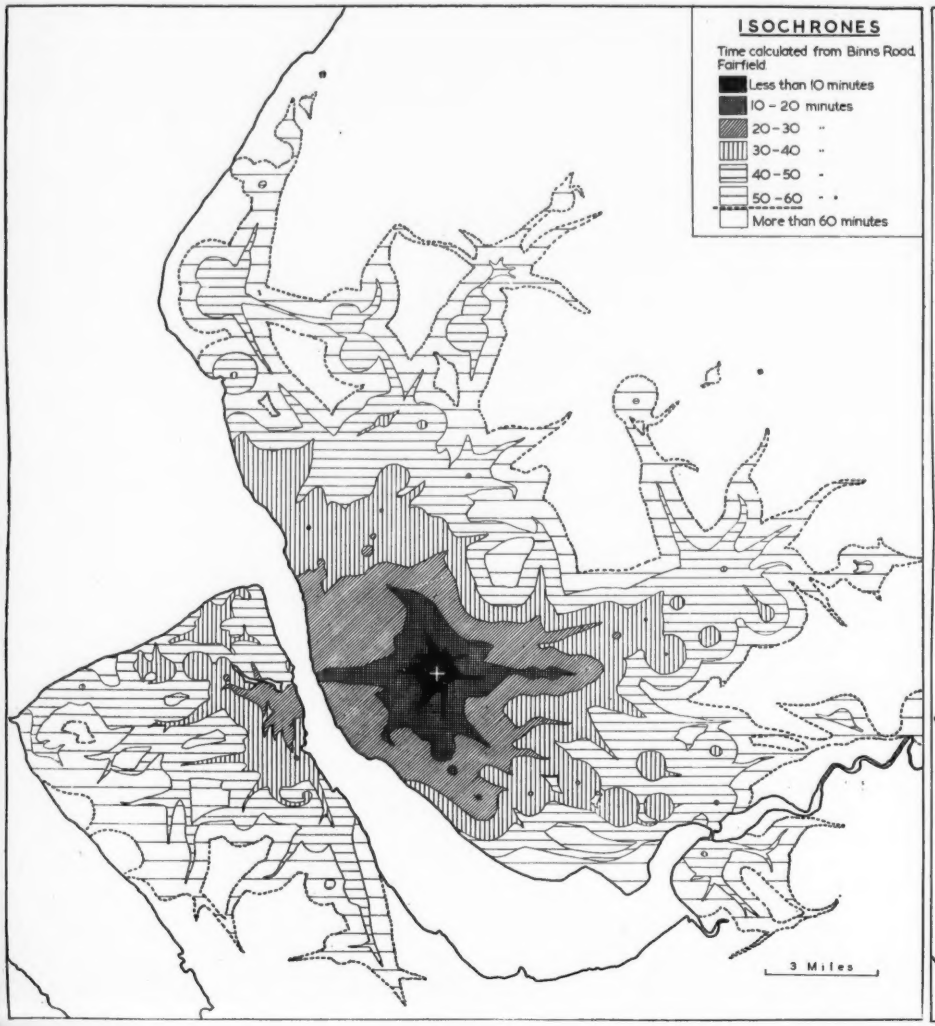

FIGURE 3

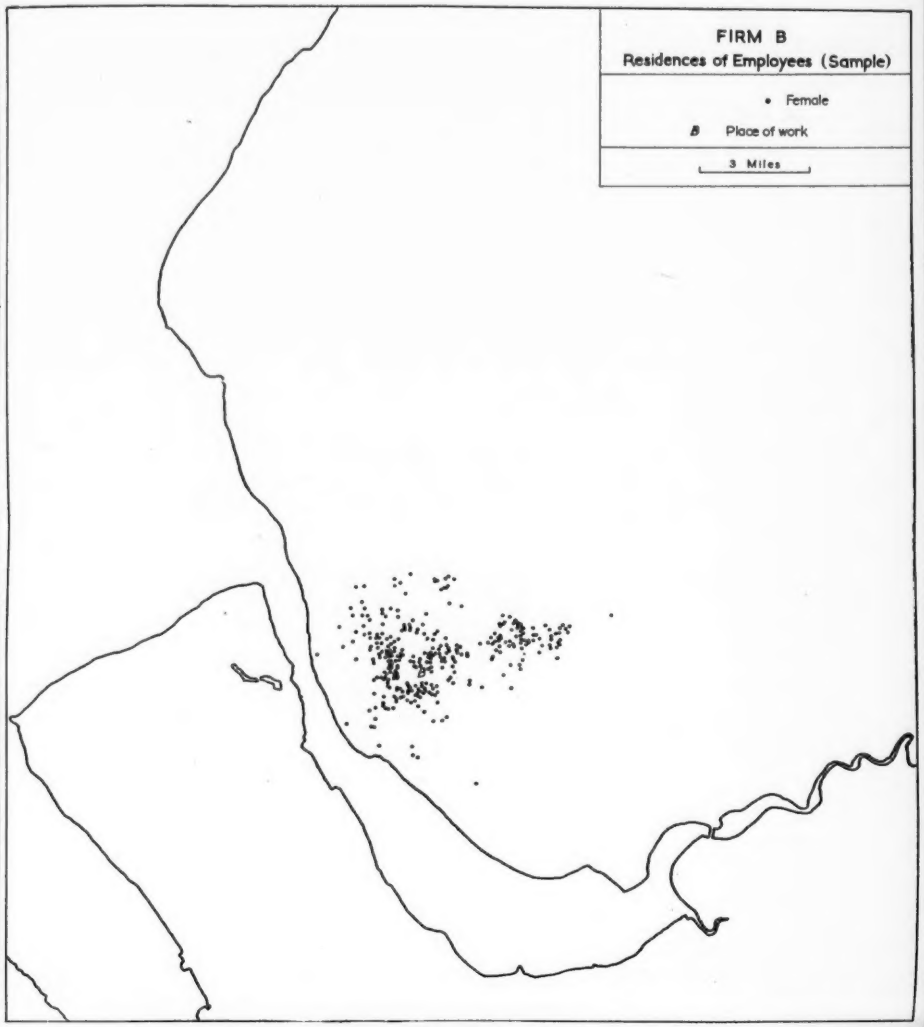

FIGURE 4

FIGURE 3

FIGURE 4

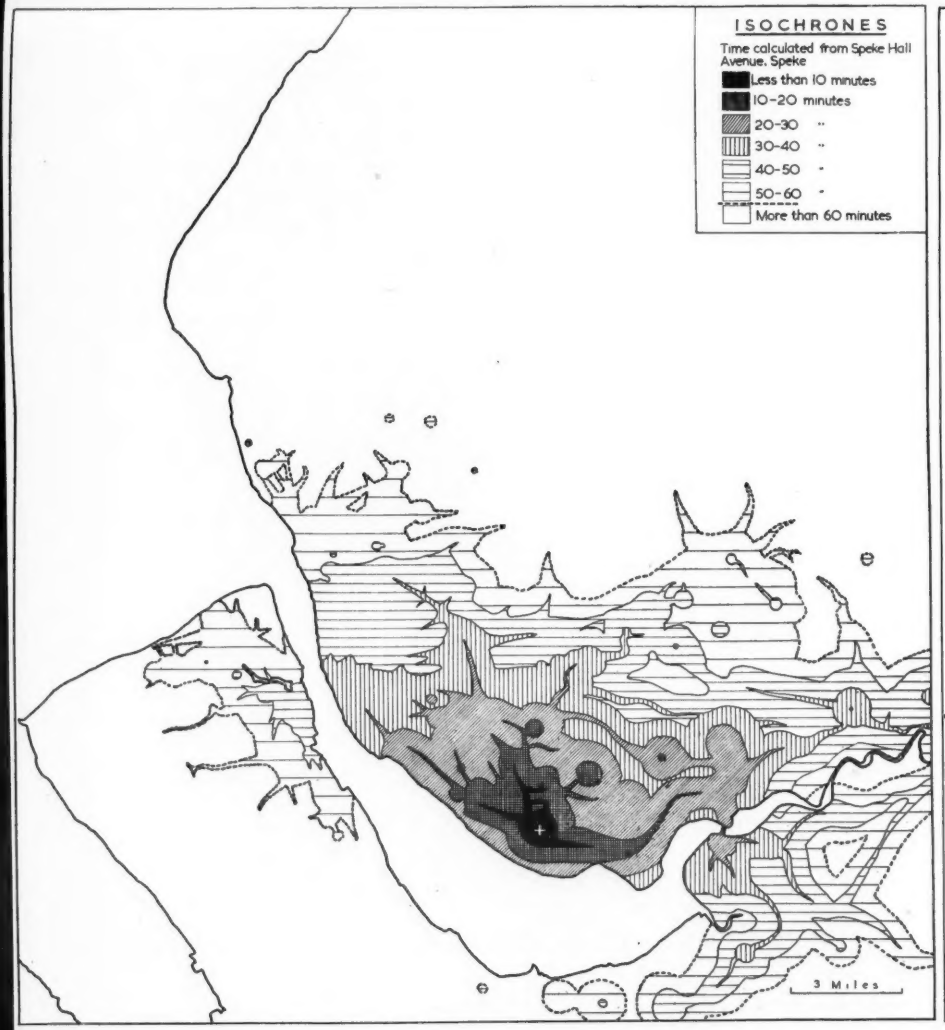

FIGURE 5

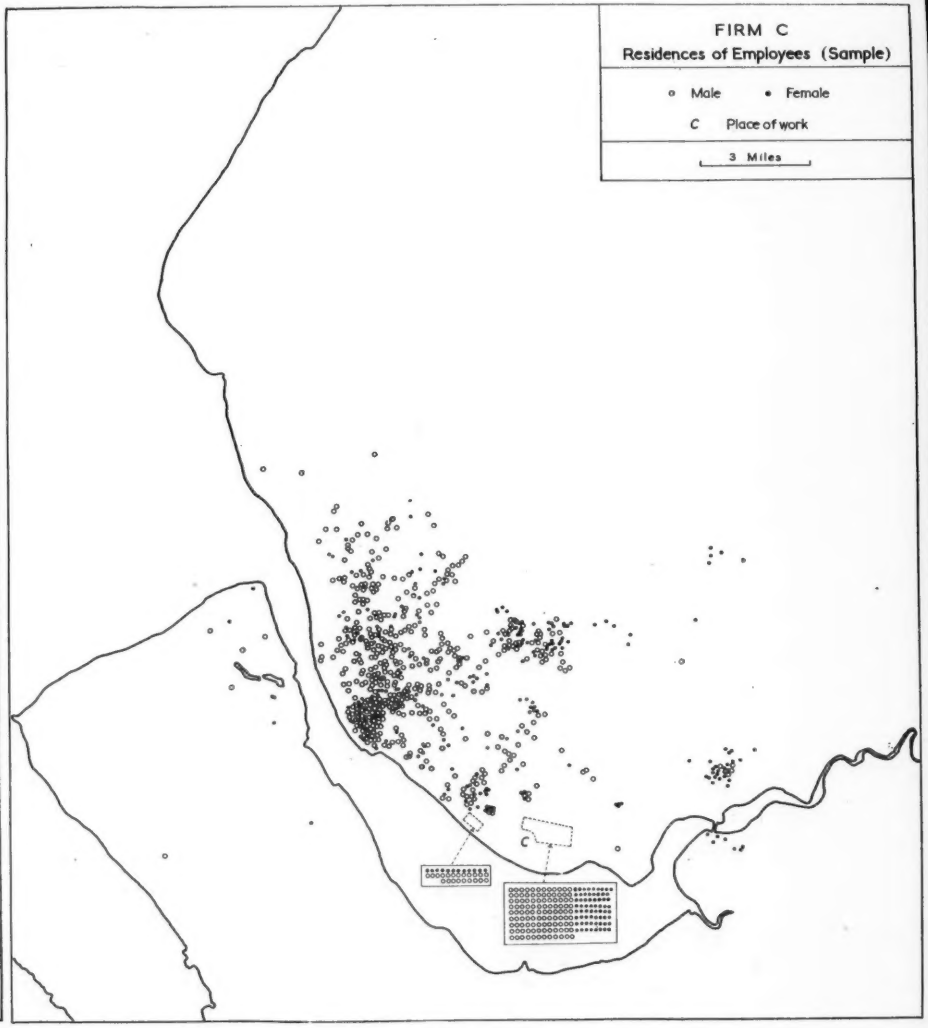

FIGURE 6

FIGURE 7

FIGURE 8

almost all the labour force for its factories. Firm B is an example of a firm within an industrial zone served, from the point of view of the journey to work, by road transport and having a compact, local labour catchment area.

The time zones in Fig. 5 are calculated from a point within Speke Trading Estate, close to several industrial firms. An interesting feature is that Widnes and Runcorn are more quickly reached from Speke than is the Liverpool city centre. The journey from north Liverpool is longer than that from Warrington. The great eastward extension of the isochrones is a result of the excellent bus services in this district, which is also served by the railway lines between Liverpool and Warrington and Runcorn.

Fig. 6 gives the distribution of the residences of a 12 per cent. sample of the employees of Firm C. Rather less than one-fifth of the employees live within 10 minutes of the workplace, that is, on the Speke Housing Estate. Only about one-quarter travel on a journey of between 10 and 30 minutes : of these, the majority lives in the densely-populated districts of Garston and Widnes. The better residential parts of south Liverpool are scarcely represented. Over half of the employees in the sample travel from 30 to 50 minutes to work. There is a compact grouping in the inner residential districts of Liverpool, particularly where housing densities are high, e.g. Dingle. Most workers in the sample taken are unskilled, and in the lower wage-earning groups, which might be expected to live in the older residential parts of the city. A large group of employees, however, lives on the newer housing estates at Huyton. Such a large labour force as this firm requires cannot be supplied from within the relatively sparsely-populated area enclosed by the 30-minute isochrone. The more densely populated districts of Liverpool are drawn on for the quantity and quality of labour needed. The distribution of Firm C's employees' residences reflects the social zones of Merseyside as clearly as Fig. 2 does in the case of Firm A : but the social zones are almost the reverse of each other. There are, as yet, inadequate residential facilities for all the employees in the new town of Speke.

Fig. 7 has been drawn with Green Lane, Tranmere (Birkenhead), as its centre. On the Lancashire side of the Mersey, the pattern of isochrones closely resembles that of the map centred on Liverpool Town Hall, with the exception that the isochrones do not extend as far outwards from Liverpool. Almost the whole of the Wirral peninsula can be reached from Birkenhead within the hour. The influence of the railway services to New Brighton, West Kirby and Chester is noticeable. The bus services appear largely as feeders to the railway, crossing Wirral transversely and, therefore, enclosing islands of relative inaccessibility.

The residences of all foremen employed by Firm E have been plotted in Fig. 8. Fifty-six per cent. of these men have a journey to work of less than 20 minutes ; another third travel from 20 to 30 minutes. Most of these employees live in the eastern part of residential Birkenhead and Bebington. Though Firm E's labour catchment area is large, a very high proportion of employees is drawn from a small area adjacent to the workplace.

The distribution maps are thus of two types. Firstly, there is the type (Figs. 4 and 8) which depicts a dense cluster of residences close to the workplace and an increasingly thin scatter as distance from the workplace increases. In these cases, the distribution pattern suggests conditions of relative social uniformity, in both a structural and a distributional sense. Other maps show scarcely any residences close to the workplace (or at middle distances) but have clusters of employees relatively far away, in Fig. 2 in suburban areas. Such maps (Figs. 2 and 6) reflect the social zoning of Merseyside. The isochrone map is of greater value as a tool of analysis for the first type of pattern than for the second, where it may merely serve to distinguish one suburban area from another in terms of accessibility. Of this second group of maps, that showing the distribution of employees with Firm A (Fig. 2) will probably change little over a long period of time ; it is a mature distribution. Firm C, at Speke, however, has a pattern which is likely to change considerably in the future. It displays an immature distribution. In this case, as more accommodation is provided in

FIGURE 8

FIGURE 7

housing estates near the site of the firm, the pattern of employees' residences may come to resemble more closely the distribution found in Figs. 4 and 8.

The isochrone maps have, it may be concluded, a definite value in relation to the problem of the journey to work. In the first place, they give a reasonably accurate estimate of the minimum time taken in the journey from any home on Merseyside to the workplace. If the assumptions upon which the maps are drawn are unreal, they are at least applied uniformly to the whole area. Secondly, it may be that particular isochrones have a certain geographical or economic significance. For example, the 60-minute isochrone calculated from the city centre seems to mark the limits beyond which firms sampled do not draw their labour supply. The *London Travel Survey* of 1949, in contrast, records 20 per cent. of a sample of London's workers as having a journey of 60 minutes and over. Further, the pattern of isochrones offers some interpretation of the transport services available. Some routes are shown to be quicker than others, even though they cover a longer distance. The predominant directions of passenger traffic flow are suggested. All this has significance in considering the relationship between workplace and residence. We cannot, however, reasonably assume that the duration of the journey to work plays a causal role in determining in all cases the choice of either residence or place of work. It may be a limiting factor when, for example, the time exceeds 60 minutes, but, for shorter journeys, other factors which the isochrone maps cannot suggest but which the maps showing the distribution of residences firm by firm do suggest, have often a far greater significance. The isochrone map is a more valuable analytical tool for a firm which is located in an area of relative social uniformity than for one whose labour catchment area includes contrasted social zones. In the latter case, mere length of journey as a factor determining the pattern of residences is often obliterated by more potent social and economic factors. The isochrone map is one tool in the analysis of the problem. It furthers one aspect of the enquiry but, alone and unsupported, it is inadequate for the full and complete analysis of the very varied economic, social and personal factors which underlie the choice of workplace, residence and the journey itself.

SECRETARY OF THE ASSOCIATION

At the end of March 1954, Mr. D. N. Lowe, O.B.E., resigns from the Secretaryship of the Association on becoming Secretary of the Carnegie United Kingdom Trust. He joined the Association's staff as Assistant Secretary in 1935 and was seconded during the war for duty as a member of the War Cabinet Secretariat. He rejoined the staff in 1946 and became Secretary on the retirement of Dr. O. J. R. Howarth, O.B.E., at the end of the short Annual Meeting held in London in that year.

Mr. Lowe is succeeded, on April 1, 1954, by Sir George Allen, C.B.E., lately Vice-Chancellor of the University of Malaya. Sir George Allen brings to the Association the benefits of a wide experience in medical research and teaching and in the administration of educational institutions. The Association is fortunate in being able to fill so satisfactorily the gap left by the present Secretary's departure and the members of the Association will wish for both Mr. Lowe and Sir George Allen every success and satisfaction in their new work.

FINDING THINGS OUT WITH RADIO AND ROCKETS[1]

by

SIR EDWARD APPLETON, G.B.E., K.C.B., F.R.S.

My address is going to be chiefly about the atmosphere above our heads and how we discover things about it, using radio waves and rockets. You will, no doubt, be saying to yourselves, 'What can there be to explore up there? When I look up into a clear sky there seems to be nothing between me and space—except the air.' However, as I hope to show you, some very remarkable things *do* happen in the upper atmosphere—although we cannot see them happening when we look up into the sky. And what is more, these happenings are of importance to us in the lives we live here on the earth—at the bottom of the atmosphere. Let me mention just two or three of these things.

You often listen on the radio to talks relayed from America. Now wireless waves travel in nearly straight lines, without bending very much. So you may wonder how the waves, sent out from America, actually reach us. Since they cannot follow the curvature of the earth we should expect them to pass high over our heads, out into space. But this is just where something in our atmosphere comes in useful. High above the earth there are electrified layers that reflect the radio waves down to us. We call these layers the ionosphere because there are free electrons and free ions in them. If these reflecting layers did not exist, long-distance communication would be impossible. So it is important to find out all we can about the ionosphere—how it is formed, how it varies from hour to hour and from day to day. As I shall tell you later, there are sometimes storms in the ionosphere when the layers are disturbed and their reflecting power is weakened. The B.B.C. announcer then tells us that it is not possible to make direct radio communication with North America.

Many other odd things have been discovered about the atmosphere. Would you believe that there is sodium in the air high over us? There is not much of it, but our experiments prove that it is undoubtedly there. Then there is also a layer of ozone which we call the ozonosphere, and this layer, which is lower than the ionsphere, is very important to us; for if it were not there, we should be so sun-burned by the ultra-violet light from the sun that life on the earth would probably be impossible unless we went about in special suits to protect us. The ozonosphere absorbs the most harmful part of the ultra-violet rays from the sun—just enough for us to be able to walk about in the sunshine without fear of damage to ourselves. On the other hand, a certain amount of ultra-violet light is essential to life, so if the ozone layer became so thick that it absorbed *every bit* of this light then, the doctors tell us, we should suffer from other troubles. So we may thank our lucky stars that the atmosphere contains an ozone layer of *just* the right strength to allow us to live comfortably on the earth.

The atmosphere is a much more complicated affair than a glance into the clear sky would suggest. We know that it extends for hundreds of miles above the earth's surface, getting thinner and thinner the higher we go, until, in the end, it merges into space, and even space, as we shall learn later, is not entirely empty.

Scientists are inquisitive creatures, and want to find out everything about the atmosphere: how cold or how warm it is at different heights; whether there are winds at great heights, and so on. We can

[1] The text of the Junior Presidential Address delivered to student members in the Philharmonic Hall, Liverpool, on Thursday, September 3, 1953.

easily tell when there are strong winds in the bottom of the atmosphere, for then we see clouds travelling along, carried by the moving air. But clouds mostly occur below a height of 12 kilometres, so that it is impossible to tell, by eye, if there is a wind blowing above that height. (Kilometres are the units used by scientists and 1 kilometre is slightly less than two-thirds of a mile.)

Then there is another question : are there tides in the atmosphere just as there are in the seas and oceans? The atmosphere is a fluid, even if it is a rarefied one, so we should expect the sun and the moon to pull it out towards them as they pull the water in the oceans to cause the tides.

But how are we to find the answers to all these questions? We can of course go up in an aeroplane or a balloon and make measurements for ourselves. Almost 150 years ago (1804) Gay-Lussac who, as you know, was interested in the behaviour of gases, went up to a height of 5½ kilometres by means of a balloon. In those days people went up in an open basket, which was very much like a large clothes basket, suspended below a balloon filled with hydrogen. When they wished to descend they pulled a rope that opened a valve which released the hydrogen slowly. It was all a rather dangerous and uncomfortable business. Ninety years ago (1862), two Englishmen, the meteorologist Glaisher and his friend Coxwell, reached a height of about 8 kilometres where they found the temperature 25° C. below freezing point. They decided then that it was about time to start coming down, but, to their horror, the valve rope had become entangled. Coxwell climbed up the rigging to disentangle it, but his fingers became frost-bitten. Meanwhile the balloon went soaring upwards and Glaisher became unconscious. Eventually Coxwell succeeded in opening the valve by using his teeth and they reached the ground in the end but in sore distress. Then, in 1897, the Swedish explorer and scientist Andrée, attempted to travel by balloon from Spitzbergen across the North Pole to Alaska. He and his companions disappeared and it was not until 1930 that another expedition found their remains and brought back their instruments and diaries. It is therefore not surprising that this tragedy in 1897 marked the end, for some time, of manned balloon ascents. However, in 1935, two courageous American Army Officers, Stevens and Anderson, went up in a balloon called the ' Explorer II,' as high as 22 kilometres, which is the present ' record ' for a manned balloon. But even that height is said to have been exceeded, in 1951, by a research aircraft of the American Navy, called the ' Skyrocket,' which the pilot, William Bridgeman, flew up to 24 kilometres. This would, therefore, appear to have been the highest level reached by man. To complete the story of ' records,' I may add that an American Army W.A.C. Corporal rocket unmanned, of course, has reached a level of about 400 kilometres above the earth ! That, in every respect, is a record !

I must now turn to some of the things which have been found out about the air at these great heights. We all know that the temperature of the air falls as we go up a mountain, and Hillary and Tensing must have found the temperature falling to round about 40° C. below zero as they climbed to the top of Mount Everest, which is nearly 9 kilometres above sea-level. Sixty years ago, everybody believed that the temperature went on falling the higher you go. But near the end of the last century a Frenchman, Teisserenc de Bort, discovered this was not so.

This scientist used to have great fun flying kites attached to steel piano wire and he attached his thermometers to the kites. On one occasion he was flying a set of eleven kites, on 8 kilometres of piano wire, when a terrible thing happened. The wire broke and the free kites trailed the wire over Paris causing all kinds of trouble. The wire fouled the propeller of a steamer on the River Seine ; it stopped a train ; it injured a gendarme who rather foolishly tried to hang on to it ; but perhaps the most far-reaching effect was that it brought down the telegraph lines between Paris and Normandy on the very day (September 9, 1899), when a famous trial —the re-trial of Dreyfus—was ending at Rennes. Now it happened that not only France, but the whole world, was eagerly awaiting the result of this famous trial. However, due to the trouble with the telegraph lines, the news of the result

was delayed a full day. ' No more kites for me,' said Teisserenc de Bort. Perhaps this was a good thing for science, because he now turned his attention to balloons to carry his thermometers aloft. At first he used, as balloons, hydrogen-filled paper bags enclosed in netting, and these carried his instruments to much greater heights than did the kites, for there was now no weight of wire to be supported. But, of course, there was the disadvantage that the balloons had to be recovered. To help with their recovery it was arranged that when the balloons burst, as they did at great heights, the instruments floated down attached to a parachute.

Now, with his balloon, Teisserenc de Bort immediately made a most important discovery. He found in 1899, that the air temperature did *not* go on falling steadily the higher you go. Above a height of about 11 kilometres, where the temperature had reached about 50° C. below zero, it remained constant. He later (1909) gave the name of troposphere, meaning sphere of change, to the lower part of the atmosphere, and the name of stratosphere to the region he had discovered.

During the early years of the present century balloon work was actively pursued in this country, notably by W. H. Dines who devised a wonderfully light instrument called a meteorgraph which actually drew a graph of temperature against pressure as it was carried up by the balloon. And it is worthy of note that the first British University to associate itself with upper-atmospheric research of this kind was Manchester, which established, at the Howard Estate on Glossop Moor, a well equipped station for the investigation of the upper air.

However, with balloons of this kind there was always the difficulty of getting back the instruments and their parachute. Sometimes it was months, even years, before they could be found. So, in the nineteen-thirties (1937, Vaisala in Finland), people began to use radio, and fixed a small transmitter with tiny batteries among the instruments carried up by the balloon. This radio set sends out signals that give, in turn, the temperature, the pressure and the humidity at each stage of the flight. These signals are received by a ground station which sometimes is also fitted with radar to measure the balloon's distance away. And, if we measure this distance at different times, we can find the rate at which the balloon is drifting, which gives us the wind speed. As can be readily understood, the recovery of the box of tricks containing the equipment is not necessary, though it is most desirable, since the equipment is expensive and one wants to be able to use it again. By the use of these balloons scientists have been able to find out things about the atmosphere well into the stratosphere—up to 30 kilometres in fact. But, of course, the scientist is never satisfied : that is part of his make-up. And, in recent years, rockets have been used to reach levels completely out of the range of balloons.

I need hardly spend much time in describing how a rocket operates, for every boy—and every girl, too, for that matter—must have set rockets off on Guy Fawkes night (using a bottle for holding them upright while the match is applied) or a ' sparkler ' or a ' golden rain ' or a ' blue-light ' or a ' Prince of Wales' Feather.' The smallest boy or girl would nowadays be able to tell me that a rocket works by jet propulsion. Bigger boys and girls, who have had to recite Newton's Laws of Motion and have done some chemistry, would tell me that some kind of fuel is burned quickly in a rocket and that the gaseous products of combustion escape rapidly backward ; and, as Newton's third law tells us that ' to every action there is an equal and opposite reaction,' the rocket shoots forward because the hot gases belch out backwards. If they went on further and said that the rate of change of momentum in *both* directions was numerically equal, I should give them full marks.

Simple rockets have been used for many years by coastguards to shoot lines to shipwrecked mariners. In the nineteenth century they were used by the British Army to hurl incendiary and explosive charges to a distance of about a mile. There was even a British Field Rocket Brigade at the Battle of Waterloo whose work has been highly commended. However, it was only during the last War that really big and efficient rockets were made. The German V2 rocket was a huge thing, weighing 14 tons fully loaded and

10 tons of this was fuel—alcohol or oil and liquid oxygen. The rocket, in fact, carries its own oxygen, and so does not need oxygen from the air for burning its fuel as an aircraft does. A rocket will, therefore, operate satisfactorily in the rarefied air at high atmospheric levels.

The important thing required in a rocket is to get the fuel burning quickly so that the downward escape of the gases gives a big upward thrust. Much work has been done, and is being done, to find the best fluids for use in propelling the rocket and the best method of feeding the propellants, as they are called, into the combustion chamber. In the V2 rocket, the 10 tons of fuel are completely burnt up in about a minute, by which time the rocket, if sent up vertically, has reached a height of 30 kilometres ; it then coasts upwards, slowing down under gravity, to a height of over 150 kilometres and then falls back to earth. The whole flight occupies about 7 minutes.

After the War the Americans used captured V2 rockets to explore the upper atmosphere above the desert at a place called White Sands in New Mexico. The rockets have been sent up carrying scientific instruments, and some of these instruments have transmitted their recordings by radio, when in flight, to receivers on the ground, while others have been automatically released from the rocket when it begins to descend and have reached the ground by means of parachutes attached to them ; and still others have been recovered from the wreckage. For it was found that if the warhead of the rocket was left on, the rocket crashed to the ground at such a speed that everything was disintegrated. But by arranging that the warhead was blown off the rocket by an explosive charge during descent, the increased air resistance to the motion of the rest of the rocket—now no longer streamlined—reduced the speed of descent so that the instruments could usually be retrieved undamaged, and used again. Actually the German V2 rockets are counted too heavy for this scientific work ; moreover they are expensive to manufacture. So the Americans have designed other types of rocket—the Aerobee and the Viking—specially for these experiments.

Now to the actual measurements themselves. The most obvious things to measure are temperature and pressure. But the rocket so compresses and heats the air through which it hurtles that these measurements are very difficult to make. However, careful experiments have shown that, just ahead of the tail fin, there is a place where pressure is the same as that of the undisturbed air. So the pressure-measuring instrument — the recording barometer—is placed there. On the other hand, it is found quite impossible to measure the air temperature directly, for the skin of the rocket is heated up to 200° C. by friction with the air. So temperature has to be calculated from the pressure reading : if we know the pressures at two different levels, fairly close together, we can calculate the average temperature of the air between those levels.

Before we consider some recent rocket results, let us remember what had been found out using the balloons. Such flights had shown that the temperature fell steadily to about — 50° C. at a height of 11 kilometres and then remained constant at that low temperature up to the highest levels reached by balloons, i.e., about 30 kilometres. But it was also found by plotting atmospheric temperatures with height, using readings from both balloon and rocket measurements—that the temperature rises again above 30 kilometres and that we get a hot layer in the atmosphere between 50 and 60 kilometres above ground. There is, therefore, a region in the atmosphere which is actually hotter than the bottom layer in which we live. The curve plotted from these readings also shows that, as we go up above the warm layer, we reach another temperature minimum—at 85 kilometres—and here, we think, is the coldest level in the whole atmosphere. This particular level of 85 kilometres is very interesting for it is the level where we sometimes see what are called noctilucent clouds. These clouds at very great heights are bluish-white in colour and are very beautiful. We do not yet know what they are made of, they may be composed of tiny crystals of ice or of dust from meteors or comets or even from volcanoes. They are so high that they reflect the light of the sun after it has sunk below the horizon. Above 85 kilometres

the air gets warmer, and it may well be that the temperature eventually rises to a value exceeding that in the warm layer at 50 to 60 kilometres. It is thought that in the outer atmosphere it may be as high as 1,500° C.

Rockets have also been used to take samples of the air at different heights. This is done by arranging that vacuum flasks open, become filled with specimens of air and then close at prearranged times during the flight. The samples are afterwards analysed and it has been found that the composition of the atmosphere does not alter much from ground level up to a height of about 70 kilometres.

Rockets have also been sent up through the ozone layer which, as I have said, absorbs and so removes much of the ultra-violet light from sunshine as it passes through it. We can tell when this has happened if an instrument which can detect ultra-violet light is carried in the rocket, because, above the ozone layer, the strong ultra-violet light is still present in the sunlight. The instrument used for doing this is called a spectrograph, as it analyses the sunlight according to the various wave-lengths in it. When the ultra-violet light is absorbed in the ozone layer, heat is produced, and it is this heat which is responsible for producing the warm layer which has its maximum temperature 50 to 60 kilometres above the ground.

Now I must leave the subject of exploring the atmosphere by means of rockets. But I hope I have said enough to show what a useful device the rocket is for finding things out about places we cannot visit. All kinds of instruments can be put in a rocket for measuring things at great heights. Scientists have used Geiger counters in rockets for studying cosmic rays. They have also used magnetometers for measuring how the earth's magnetic field falls off in strength as distance from the earth increases. But one of the nicest things scientists have done is to send up continuously operating cine cameras. A picture taken by such a camera at 130 kilometres shows the curvature of the earth quite clearly enough to convince anyone—if there is such a person nowadays—who still thinks the earth is flat !

I now turn to the use of radio waves for probing the atmosphere and finding things out about places we cannot visit. The great advantage of the radio method of exploring things is that it is relatively cheap, while rockets are expensive : you cannot be shooting rockets all the time, but you can look for things by radio without stopping. In this way you can be sure that, if unusual things happen in the atmosphere, you can detect and record them.

Everyone knows nowadays that we can detect things like aircraft and ships by radar, which works because aircraft and ships reflect radio waves, that is, because they are solid objects. A concentrated beam of radio waves is sent out by a radar station, and if this beam falls on a solid or liquid object, a small fraction of the radio energy is reflected back to the radar station where it can be detected. We know then that there must be some solid or liquid body in the direction in which our radio beam is pointing. But radar does more for us than that, for, besides giving us the direction in which the reflecting body lies, it also gives us the distance away in that direction. To achieve this, the radar station sends out a continuous succession of short pulses—or jabs —or spurts—of radio waves. Each pulse produces its own echo by way of the radio reflection, and so we get back a succession of echoes. But, of course, each echo comes back a short interval after the pulse which produced it was sent out. We call this short time the echo delay time.

You use the essential principle of radar when you clap your hands some distance from a cliff and listen for the echo of the clap by way of reflection from the cliff. You can recognise the delay, in that case, by ear, for sound waves do not travel very fast. But radio waves travel a million times as fast as sound waves, so, in radar, we have to use very rapid methods of detecting and timing the echoes from reflecting objects. Yet these things, and much more, can be done by electronics. Usually the radar beam is arranged to rotate steadily looking at all directions in succession. Then it is possible to display, on the radar screen, all reflecting objects within range with their distances and their directions correctly indicated as on a map.

But although radar is now well known because of its use in the War for detecting enemy aircraft and ships, and afterwards for assisting peace-time navigation on land and sea, the basic method of radar was developed, and first used, for exploring the upper atmosphere. Using what we may call scientific radar, the ionosphere was discovered in 1924 and 1925. This is, as I mentioned, the shell of free electricity, high up in the atmosphere, which consists of free electrons and ions. An ion, by the way, is an atom or molecule which has had an electron chipped off it. To investigate the ionosphere we send our beam of radio pulses vertically upwards and we usually receive the echo pulses at the same station and almost always on the same aerial. Echoes coming back from the ionosphere can be quite strong. Very often the echo waves bounce on the ground and go up again to the ionosphere, and we then get what we call multiple echoes. From the delay time between the sending-out of a pulse and the arrival of its first echo, we can calculate the time of travel of the waves on their up-and-down journey. Then, knowing the speed of radio waves (which is the same as the speed of light) we can estimate the level at which the waves have been reflected. For example, if the echo comes back after a thousandth of a second, we know the waves have been reflected at a level of 150 kilometres above the ground.

By making height measurements of this kind, scientists have been able to find the heights of the reflecting layers in the ionosphere. But, from a practical point of view, we want to know the range of radio wave-lengths which the ionosphere will reflect. We know, of course, that the ionosphere will not reflect all wave-lengths, because light from the sun can pass straight through the ionosphere and light waves are really the same things as radio waves only their wave-lengths are many million times shorter. We can show, in a theoretical calculation, that short waves penetrate an ionospheric layer more readily than do long waves. So we can experiment with our radio pulse-equipment, starting first with long waves, which are reflected, and then going gradually to shorter and shorter wave-lengths. At a particular critical wave-length we find that our echo disappears and we know then that the layer has been pierced. This critical penetration wave-length is an important quantity, since once we know it, we can calculate the electron concentration, that is, the number of electrons per cubic centimetre in the densest part of the layer.

I can put all this for you in another way, using an analogy. Let us suppose that over our heads there is a horizontal net, with all its holes exactly the same size. To get some idea of the size of these holes without actually measuring them we could throw balls of different sizes vertically upwards, to see if any of them would go through the net. Starting with large balls first, we would find them coming back to us—being reflected that is. As we used smaller and smaller balls we would eventually find one that would just go through the holes and not be reflected at the surface of the net. That would be what we call the critical size—and this would correspond, in the ionospheric case, to the critical penetration wave-length.

In actual practice we usually speak of critical penetration *frequency* rather than critical wave-length. There are over a hundred stations in different parts of the world finding these critical frequencies for the different layers of the ionosphere every hour of the day. These are radio pulse stations which automatically switch themselves on every hour and then change their radio-frequency continuously over a wide range. The radio echoes are registered on photographic paper and next day this paper can be developed and we can find the values of the critical penetration frequencies at each hour. I remember starting to make measurements of this kind, over twenty years ago, but I had to stay up all night for the purpose. Nowadays we have automatic equipment for this work which records the measurements while we sleep.

Having got the value of the critical frequency for any particular layer, we can calculate by a reliable theory, the electron population in the densest part of the layer. We have found that there are two layers, the E Layer and the F Layer ; though sometimes we distinguish between the lower and the upper parts of the F Layer by calling them the F1 and the F2 Layers

respectively. In the E Layer at mid-day we may have a maximum electron concentration of 100,000 electrons per cubic centimetre; while in the F2 Layer we may have ten times that figure. However we usually find the F2 Layer to contain the strongest concentration of electrons. It is therefore the most important layer from the standpoint of practical radio communication due to the influence of the ionosphere, for it will reflect the shortest wave-length.

As soon as we learned how to investigate the ionosphere by critical penetration frequency methods, and so were able to measure electron concentrations, it was possible to make some progress in understanding ionospheric phenomena. We could find out, for example, how the electron concentration varied throughout the day, and we discovered that there were always more electrons in the ionosphere at noon than at midnight. This gave us a hint that ultra-violet light from the sun might be responsible for producing the ionosphere. This hypothesis was first proved by some experiments made by the critical-frequency method during a total eclipse of the sun, in 1931. It was found that, as the moon covered more and more of the sun's disc, the electron concentration in the ionosphere was reduced. This meant that the moon was cutting off the solar radiations which were the cause of the ionosphere, and we infer that such radiations consist of ultra-violet light.

As we have now been measuring electron concentrations in the ionosphere for over twenty years we have got to know a great deal about ionospheric variations. We have been able to show, for example, that the electron concentrations in the various layers increase in the course of the sunspot cycle, which must mean that when there are plenty of sunspots the ultra-violet light emitted by the sun is specially intense. We have, however, suspected now for many years that electrified particles as well as optical waves are emitted from sunspot areas on the sun's face. We think that, sometimes, both particles and waves are erupted at the same time and both, in due course, reach the earth's surface. But the optical waves in both the visual and ultra-violet parts of the spectrum travel from the sun to the earth in about 8½ minutes, whereas the electrified particles arrive over a day afterwards. There is a kind of race across space and the light waves beat the particles easily. When the optical waves reach the earth the astronomer can see what we call a solar flare near a sunspot area. When the particles reach the earth they cause a magnetic storm and often also a display of the aurora of northern lights. Our ionospheric measurements also show us that, during a magnetic storm, the ionosphere is churned up and disturbed; we call such conditions an ionospheric storm. So it is possible to understand how big magnetic and ionospheric storms often occur about a day after a bright solar flare has been seen.

Some years ago Dr. J. S. Hey and I discovered that very often when a solar flare occurs there is a strong burst of radio waves from the same sunspot area. The radio emission from the sunspot area is so intense that the waves can be detected after travelling all the way from the sun to the earth, which is a distance of 93 million miles. Nobody knows quite how these radio waves are generated, but some Australian scientists have suggested that they are produced in some way by the electrified particles, emitted by the sunspot area, as these particles make their way through the sun's own ionosphere. For the sun, like the earth, has an ionosphere which we call the solar corona. It can be most easily seen by the naked eye at the time of a total eclipse of the sun. The Australian scientists have detected these bursts of radio noise on different radio wave-lengths, and they believe that, in that way, they have been able to measure the speed of the electrified particles as they rise up from the sun, through the corona, and out into space. I cannot go into the details of this experiment now, but it depends on the fact that the sun's ionosphere will only allow radio waves of greater frequency than a certain value to escape from a particular level in it. For example very short radio waves can escape from the bottom of the corona, but longer radio waves can only escape from the highest levels of this solar ionosphere. However, the really important thing for us is that the Australian experiments suggest that the electrified particles travel

through the corona with a speed of about 1,600 kilometres per second, which is about the speed necessary to cause these particles to take about a day to travel from the sun to the earth. It looks as if we can now witness, by radio means, the actual birth of a magnetic and an ionospheric storm.

So far I have been dealing with the use of radio for helping us to understand the effects of solar radiations on our own atmosphere—but there are other things which invade our atmosphere at high levels. I refer, of course, to meteors or 'shooting stars' as they are often called. These things come without warning, flame through the sky and disappear. Each is due to a very tiny speck of sand or gravel which plunges into our atmosphere from outer space and usually gets burnt up in doing so. If it is big enough for this *not* to happen and it actually reaches the ground, we call it a meteorite. We cannot, of course, see the meteors themselves because they are so small : all we can see is where a meteor has been—by the trail of light it produces as it burns up due to the heat caused by friction of the air.

For many years the subject of meteors was studied by visual methods which had limitations. For one thing, meteor trails can be seen only on clear, moonless nights : they are invisible during the day. Also, they are over in no time, and it has been difficult to measure their speeds accurately. However the introduction of radar methods of investigating meteor trails has revolutionised the subject, clearing up many doubtful points. Radio waves are reflected by meteor trails, that is by the strokes of luminosity we see. The meteor trail can be considered as behaving like a long reflecting aerial of wire, and although the radio echo it throws back does not usually last longer than a few seconds, even that short time permits the radar set to indicate the distance away. Radar methods have also been used to measure the speed with which the bright trail develops, and this gives the speed of the meteor itself. I ought to stress the fact that the tiny meteor particle is too small to be detected by radar. It is only the electrified meteor trail which gives the radar reflection, but that is sufficient for most purposes, and we have the special advantage that the radar method of detection will work at any time—on cloudy nights and in full daylight. Since 1946 some most important work on this subject of the radar detection of meteors has been carried out near Manchester—a town not famous, I think, for its clear skies—by Prof. A. C. B. Lovell and his associates. They have, for example, discovered a series of intense *day-time* meteor showers which occur in May and continue till the end of July. Observers who had previously had to rely on their own eyesight had, of course, no idea that these day-light showers occurred at all. But, to my mind, the most important result of the Manchester University work has been the accurate measurement of meteor velocities. We have long wanted to know whether meteors, which are the debris of outer space, belong to our own solar system or not. Astronomers have calculated that, if a meteor has a speed of less than 72 kilometres per second it must belong, as the earth does, to the solar system. On the other hand, if the speed of a meteor is greater than 72 kilometres per second it possesses enough energy to overcome the gravitational pull of the sun and so escape from the solar system. The Manchester scientists have measured the velocities of many hundreds of meteors and have never yet measured one exceeding 72 kilometres per second. It therefore looks as if we can picture all meteors as being subject to the gravitational control of the sun and therefore as being members of our own solar system.

I mentioned earlier that radio waves are reflected by liquids as well as by solids. So a radar station can be used to detect drops of rain as they are falling. We cannot detect a single drop of rain by radar but we can detect the combined reflections from the many drops which make up a heavy rainstorm. Thus radar may be used to locate regions where rain is falling within an area of several thousand square miles surrounding the observing stations. This is particularly important for finding the position, direction of movement and the speed of hurricanes so that ships and coastal stations may be warned of their approach.

We have considered just a few of the things that we are finding out with radio

and rockets. But, of course, there will be much more to tell you in ten years' time and still more in twenty years' time, and so on. In science, progress never stops : that is the fascination of it. You may be sure that many further exciting things will come from experiments with rockets. One trouble with present rocket work is that the projectile does not stay long at its greatest height and it has been suggested that, if we could get a rocket high enough, so that the resistance of the air becomes quite negligible, we could make it travel round the earth at a constant height. In such a case the rocket would become a satellite of the earth—like the moon, but of course not so far away. The scientific basis of this is all quite sound because we can picture the attraction of the earth on the rocket just balancing the rocket's tendency to fly away due to centrifugal force. Gravity would then be neutralised at the level of the rocket and there would be no such thing as weight as we know it. Of course the nearer to earth the satellite is situated, the faster it would have to travel to maintain these conditions. One can calculate that an orbital rocket of this kind would have to travel round the earth in 2 hours if its height were 1,669 kilometres, whereas it need only travel round earth in 24 hours if its height were 35,900 kilometres. People have designed multiple rockets—in theory, that is—to reach the lower of these two great heights—one rocket taking the assembly up a certain distance and then setting off a smaller one and so on. The overall weight required, again in theory, comes out at 7,000 tons, the weight of a light cruiser. Nearly all the weight is due to the fuel, and the weight of the part which finally arrives at the required height is 24 tons. Even the cost has been estimated and that comes out at 4 million dollars per orbital rocket !

Some of the more enthusiastic people who write on space travel assume all this to be easy and then go on to picture a fleet of orbital rocket ships travelling round the earth ; these are to serve as a kind of space terminus station for trips to the Moon, to Mars, and so on. Pictures are shown of men at these orbital ship stations moving about outside in space suits. They must, of course, be tied to the space ship to ensure that they keep up the necessary speed. Inside the space ship which is supposed to be pressurised one might think that life would be fairly normal. But just think of what would happen if you tried to have a meal. You could use a weightless knife and fork, I think, but it would be most amusing to try to use a spoon because food, having no weight, could not be expected to stay on it ! Perhaps sugar-tongs or chopsticks would be the most useful ! It is all very amusing to think about, so long as you do not lead people to believe that all this is round the corner.

No, a great many unknown factors must be examined before we can picture a human being coasting round the earth in an orbital space ship. One question is whether ' space man ' can survive such an experiment. Can he stand the acceleration necessary to send him to these great heights ? Can he stand the exposure, for any length of time, to the heavy cosmic rays from which we are protected at ground level by the atmosphere ? What is the chance of the space ship being punctured by a heavy meteor and so on ? Clearly far more experiments will have to be done with rockets containing instruments, and then with living animals, to try to settle these questions. In fact, monkeys have travelled up in rockets to a level of 130 kilometres, and do not seem to have been unduly perturbed by their experience.

Then we have always to think of the possibility of some new scientific discovery that would alter completely our present way of thinking : the discovery of some new rocket fuel far more efficient than our present ones and so on. Scientists will proceed to these matters slowly, checking up this point and that before hazarding any human journey beyond our atmosphere. What I think is so foolish is to ask a scientist to tell you how long it will be before one can take a ten-day trip round the moon and have a look at something no human being has ever seen—the back face of the moon ! And still more foolish is the scientist who tells you that this will all certainly happen within twenty or fifty years' time. I myself read every serious book I can get hold of on the topic of space travel for I find it a fascinating subject ; but I would not dream of

hazarding a guess in these matters, just because we cannot predict the future of developments in science—developments which might alter completely our present-day ideas on this subject.

So far we have considered the peace-time uses of radio and rockets, but we must remember that both radio and rocket can be used, in war, to kill people. That is what happens with scientific knowledge ; it can be used for good or ill. Let me give you the simplest of examples to illustrate this point. Over the last twenty-five years the radio-scientist has developed efficient methods of broadcasting over short and over long distances. We, therefore, have means whereby nation can speak to nation. However, the radio-scientist, so to speak, hands over the microphone to other people, who can broadcast good or evil things as they please. The same radio installation can be used to transmit, to a distant people, in their homes, truth and goodwill ; or it can be used to convey untruths, to breed suspicion and engender hatred. Yet it is the same microphone in the two cases. But, of course, it is not the scientist's business to dictate how his discoveries are used, and I think it would be wrong of him to refuse to develop new things because those new things might be used in the wrong way.

So let me leave this last thought with you. We must look on the gifts we get from science as charging every one of us with a great responsibility : the responsibility of using them for the benefit, and not the ruin, of our fellow men.

PREVENTIVE MEDICINE AMONG FARM LIVESTOCK

At the Liverpool Meeting of the Association, Section M (Agriculture) devoted the morning of September 7 to a discussion on preventive medicine among farm livestock. Prof. E. G. White, University of Liverpool, in an introductory paper, illustrated some of the ways in which farm animals can be protected against diseases, whether introduced from abroad or established in Great Britain. Mr. J. N. Ritchie, Ministry of Agriculture and Fisheries, discussed the contribution of the State to disease prevention and control. Dr. E. L. Taylor, Ministry of Agriculture and Fisheries, considered the influence of parasitic diseases on animal production. The symposium ended with a contribution from Mr. J. O. L. King, University of Liverpool, on the influence of animal husbandry on disease.

The papers are printed below in full.

Preventive Veterinary Medicine among Farm Livestock

by

Prof. E. G. White

My task is to introduce the subject in general terms, leaving my colleagues to deal with those aspects in which they have a special interest—State medicine, animal husbandry and parasitic diseases.

The World Food Shortage

The greatest problem of the next generation may be to produce enough to eat. World population is increasing at a greater rate than world food production, and an era of world peace may well cause an even greater disparity unless we can turn swords into ploughshares and spears into pruning hooks. This means spending the effort and money we had to devote to wars in getting acres into cultivation and in producing more food per acre. In many countries much valuable land is being lost by soil erosion and everywhere land used for growing food has to be diverted to other uses. Great areas of potential agricultural land cannot be used for food production because animal disease like trypanosomiasis, cattle plague or tick-borne infections are rife. In many parts of the world the standards of breeding, feeding and management, along with tribal customs, result in the keeping of large numbers of stock of very low productivity. But this world view of food production is too large to be considered in any detail to-day. Instead we must confine our attention to Great Britain, where fifty million people produce enough food for thirty million and where the aim is to increase food production by 1956 to a level 60 per cent. higher than pre-war, instead of 40 per cent. higher as it is now.

Preventing disease in livestock increases and prolongs their productivity and is thus one way of increasing food production. By producing more food at home we can help other countries as well as ourselves.

Veterinary preventive medicine means, quite simply, *keeping animals healthy by preventing disease*. It is not restricted to preventing disease caused by infective agents, such as bacteria, viruses, protozoa or animal parasites; it covers a much wider field, embracing the prevention of nutritional and metabolic diseases and poisoning, the avoidance of methods of housing and management which favour disease, and the careful selection and control of animals used for breeding.

Prevention is Better and Cheaper than Cure

Prevention is not only better than cure ; it is usually cheaper. Since veterinary medicine as applied to farm animals is still governed by the price which the farmer, or in some cases the State, can afford to pay, it is clear that cost is an important factor.

In contrast to preventive medicine there is curative medicine, by which diseases are relieved by medicinal or surgical treatments and animals are restored to health and productivity. Unfortunately, it is not always possible completely to repair the damage that tissues and organs have sustained. Quarters that have been damaged by mastitis may take a long time to recover their original secretory activity, and they may never do so ; sheep with parasitic gastritis or enteritis or fluke infestation may be too weak to tolerate an anthelmintic : and animals with a vitamin deficiency may succumb to a secondary bacterial or virus infection because their resistance has been lowered. Furthermore, we can often prevent disease even when we have as yet no means to cure it, or do not even know its cause. Thus, in the latter half of the nineteenth century diseases like sheep pox, cattle plague and pleuropneumonia were eradicated by restricting importation, and by quarantine, slaughter and sanitary measures long before the causes of these diseases were known.

Some Diseases and Ways of Preventing Them

A century ago the prevention of disease among farm livestock consisted mainly in controlling the great animal plagues, which the movements of men and animals, especially in wars, transmitted from one country to another. Little was known of nutritional diseases ; bacteria, viruses and protozoa were not yet discovered ; and diseases were recognised essentially by their spread and by the deaths which they caused. In some less developed countries preventive veterinary medicine is still very much at this stage. The main effort there is devoted to controlling infectious diseases and there is little opportunity to deal with internal parasites, nutritional deficiencies or disorders of metabolism. Feeding and management are still primitive and yields of milk and meat are low.

In this country we have long since eradicated cattle plague, sheep pox, glanders and pleuropneumonia, but some diseases still come to us from abroad—foot-and-mouth disease, fowl pest and anthrax are examples. Rabies is kept out or limited to quarantine kennels. Of the diseases which are enzootic, we have done much to control mastitis and abortion in cattle, many of the diseases of sheep caused by the anaerobic spore-bearing bacteria (lamb dysentery, braxy), nutritional diseases caused by lack of minerals, vitamins or trace elements in poultry and pigs ; and we are well on the way to eradicating bovine tuberculosis. The next stage is to try to prevent the diseases that remain—infertility, metabolic disorders, Johne's disease, fowl typhoid and a whole host of other conditions which have not so far entirely yielded all their secrets and to which more attention needs to be given.

The methods used to prevent disease depend on the causes of those diseases, their ways of introduction and spread, the ease with which they can be recognised and the cost of controlling them. With diseases like foot-and-mouth, in which infection comes always from abroad, attention is concentrated on preventing the virus getting into Britain by control of imported animals and animal products, destroying the virus when it arrives or at least keeping it away from susceptible stock, and eliminating all animals which develop infection or are in contact with affected stock.

With some infective diseases the causal agent lives in the soil and cannot be entirely eliminated. The main method of prevention in such diseases is to protect the animal by the use of vaccines which give an active immunity. Tetanus, lamb dysentery and blackleg are examples.

Then there are diseases like swine fever and fowl pest which are introduced from abroad from time to time but are perpetuated by the traffic in animals and by raw animal products. The boiling of swill and its separation from stock until it has been boiled is one way of preventing

spread of these diseases. The recent campaign to encourage vaccination of pigs, in the face of a greatly increased incidence of swine fever, is another. The restrictions on infected premises and on markets is a third method. With the great rise in the pig population and the increased traffic in pigs swine fever has become very widespread in recent months and vigorous steps are needed to control it effectively. Rapid and certain diagnosis is also a problem here, for the virus which causes the disease does not always produce lesions that are characteristic.

With parasitic diseases, the problem is rather different. In the case of most internal parasites which cause losses in farm stock we cannot hope entirely to avoid their development in the animal: our aim at present is rather to limit the size of the infestation by strategic treatment and by appropriate methods of management and also to help animals to withstand the ill effects of the parasites by giving them an adequate diet. This means well-fed animals, exposed to a limited infestation of internal parasites and regularly treated with anthelmintics. Perhaps in no other type of disease is prevention so much better than cure.

Proper nutrition is of importance also in its own right, by preventing specific nutritional deficiencies. The prevention of swayback in lambs by feeding copper to the ewes, or of anaemia in young pigs by giving a supply of iron are two examples from among many. The last fifty years have seen tremendous advances in our knowledge of the nutritive requirements of animals and much can be done to prevent deficiencies of minerals, trace elements and vitamins.

When we turn to poisoning, we find another good example of the value of preventive medicine. Some ten years ago I pointed out the danger of lead poisoning in calves. To illustrate the extreme toxicity of lead for calves under certain conditions, I recorded the death of a calf from acute lead poisoning seven days after it had been given one-third of an ounce of paint scraped from one square foot of a painted door used as a partition in a calf pen where animals had recently died suddenly. Others have since stressed the same danger. And yet lead poisoning in calves is still all too common.

Of recent years much attention has been given to fluorosis in livestock on farms near certain types of industrial plant. Fluorine poisoning has recently been said to be a serious menace in the Rotherham district. Vegetation is not affected as the contamination is superficial. Stock can be protected only by keeping them housed for long periods. It is odd to recall that in an area where fluorosis is serious among farm stock it is proposed to add fluorine to drinking water in order to protect the teeth of children from caries !

Water is of great importance in the prevention of disease. On the one hand, a piped water supply helps farmers to produce clean milk and to reduce the concentration of disease-producing agents. On the other hand, water may help to perpetuate and spread disease. The farm pond, in which animals defaecate, provides a favourable site for the survival of the organism of Johne's disease ; damp places favour the survival and development of a variety of internal parasites and their intermediate hosts, such as the snails that harbour the liver fluke, or the infective stages of gastro-intestinal worms and lungworms.

In 1952 it was estimated that 97 per cent. of farm water came from wells or springs. The provision of main water to farms, the fencing of ponds and the drainage of wet land are important ways of improving animal health and increasing farm efficiency.

Losses Due to Disease

Having indicated some of the ways in which diseases are produced and some of the methods of preventing them, let us turn to the losses they cause. Many estimates of losses from diseases of livestock have been made, both here and abroad. But in the absence of reliable statistics they must be merely guesses. Except for the notifiable diseases, we have few adequate records of the losses from disease or their precise causes. In 1952 the Ministry of Food recorded a loss of £414,000 on the sale of hides damaged by the larvae of the warble fly ; to this must be added the loss of milk and condition resulting during

the animals' life. If farmers dressed their cattle for warbles during the prescribed season these losses would be very greatly reduced and the warble fly largely eradicated from many areas. In 1951–52 the cost of controlling foot-and-mouth disease amounted to some three million pounds in compensation, together with the costs of operating the eradication campaign. So massive an epidemic could not be anticipated and may not occur again. Since we believe that infection came from the Continent, perhaps through birds, there may be some hope that the endeavours of F.A.O. to promote an international scheme for control of the disease may eventually benefit us. But it is difficult to convince countries which regularly have large outbreaks and do not adopt the slaughter policy to take steps designed to protect our own island, where every bovine is fully susceptible and where freedom from the disease is essential for our continued export trade to various parts of the world.

In 1940 it was estimated that mastitis, contagious abortion and sterility caused an annual loss of twenty million pounds. Thanks to penicillin and other antibiotics for mastitis, Strain 19 vaccine for contagious abortion and better knowledge of reproductive disorders, aided by the use of artificial insemination, the incidence of all three diseases has been reduced although much remains to be done. Temporary freedom from such diseases, however, tends to make stockowners careless and it is necessary repeatedly to warn against the recurrence of abortion, for instance, if vaccination is not practised.

For animal diseases we have no system of records like that which the reports of the Registrar-General provide for human diseases. Knacker's yards, to which so many sick animals go, give us no information. Abattoirs, which for the most part lack veterinary inspection and facilities for laboratory study, provide records which are quite inadequate. Veterinary practitioners seldom record their cases. There is an urgent need for more adequate records of the incidence of disease and the causes of death. For only by knowing just what diseases exist, where they occur and how common they are can we properly apply the principles of preventive and curative veterinary medicine.

When estimates are made of losses from disease among livestock—one estimate is some eighty million pounds a year—it is often assumed that all this is preventable. Now although we know much about disease and its prevention, it is certain that not all of it can be prevented ; the estimate we really need is that for preventable disease. And if every major disease existing among livestock to-day were entirely prevented, other diseases which we had not noticed, or which had been suppressed by the diseases which formerly were rife, would take their toll. Furthermore, even the best methods of prevention are rarely 100 per cent. effective.

Cost as a Factor in Disease Prevention

Veterinary medicine differs from human medicine in that farm animals have a definite monetary value. The cost of preventing and controlling disease must therefore, if the farmer has to pay for it, bear a direct relation to the losses it can prevent or the cures it can effect. When the State controls disease, this does not necessarily apply, for it is the general taxpayer who meets the cost of controlling the notifiable diseases, eradicating bovine tuberculosis, or preventing disease in Accredited flocks. When the farmer has to pay direct for control he naturally has to consider its cost. What may be reasonable for a thoroughbred horse or a valuable bull may be uneconomic for a farm horse. Whereas the owner of a pet dog may willingly pay a couple of guineas to have it protected against the risk of contracting an infectious disease, a farmer may consider that a few pence per head for his flock of sheep or poultry is too much to spend unless the risk of disease is seen to be great.

The Changing Pattern of Disease

The disease pattern is continually changing. Control and prevention of diseases of young animals increase the period of survival of the population and alter the disease pattern so that eventually

more of the diseases which affect older animals occur. Just as people who a century ago might have died when young from typhoid or smallpox or diphtheria now live longer and may eventually succumb to heart disease or cancer, so calves which no longer die of calf scours or young beasts protected from contagious abortion may later succumb to Johne's disease or metabolic disorders. Our concern is particularly with those diseases which reduce the productivity of animals by preventing survival to adult life, reducing the yields of milk, meat or wool, or preventing the production of healthy offspring at regular intervals.

The Attested Herds Scheme and the establishment of eradication areas is the greatest of all our animal health projects. It was long overdue and some other countries have shown us the way. But I leave it to Mr. Ritchie to deal with this disease.

How Farmers can Prevent Disease

Preventive medicine is a task for the combined efforts of farmer and veterinary surgeon, Ministry official and private practitioner alike. The prevention of the introduction of disease from abroad is the sole concern of Ministry veterinarians, who also see that animals exported from Britain do not take our diseases along with them. All notifiable diseases are controlled by the State but the farmer can do much to prevent their introduction to his own premises and their spread to others. The prompt notification of disease; the isolation of newly purchased animals to allow time for disease in the incubative stage to show ; the careful storage of raw swill and its efficient heating to destroy disease-producing agents ; special care with the comings and goings of animals and of people when infectious disease is rife in an area ; good feeding and regular dosing to prevent internal parasites from producing harmful effects ; care in the selection of breeding stock ; separation of young animals from older ones and of sick from healthy ; regulation of grazing in the interests of nutritional efficiency and parasite control. These are some of the things that farmers can do. To them must be added the well tried methods of protective inoculation, such as those for abortion, swine fever and several sheep diseases, which can be carried out at a cost which is low when compared with the cost of treating the disease when it occurs. Finally there are the simple precautions to prevent mineral and plant poisoning which is still all too common. Measures like these, applied by the farmer with the advice and assistance of his veterinary surgeon, would greatly reduce the losses from disease and bring us nearer to the goal which has been set for British agriculture.

Although the cure of disease and the alleviation of suffering are very necessary tasks, the first duty of medicine is not to cure disease, but to prevent it. But whereas the successes of curative medicine are easily measured, the real triumphs of preventive medicine are not, for they are the things that do not happen.

The Part Played by the State in Controlling Animal Diseases

by

J. N. Ritchie

In Great Britain the control of important animal diseases has been exercised over many years under legislation which requires that owners report their suspicion of disease to the police. The responsibility for this work rests with the Ministry of Agriculture and Fisheries and extends to England, Wales and Scotland.

Diseases which have been made notifiable comprise those which spread rapidly, involve serious loss to agriculture or have some Public Health significance. The primary aim is to eradicate the disease completely, and in the meantime to keep it under control ; and to protect the public health where necessary. Before a disease can be made notifiable, which means that a legal obligation is placed on the farmer to report the suspected presence of certain symptoms, the Department has to be satisfied that the farmer can reasonably be expected to notice the symptoms and that the disease is capable of accurate diagnosis. Measures must be available for preventing spread of the disease, for its prevention or cure, and for ensuring that

infection no longer exists on an infected place from which movement of stock is restricted.

Notifiable diseases include several which are no longer present in Great Britain. Two important diseases of cattle are included: Rinderpest, which is still the greatest killing disease of cattle known, was eradicated in 1877; and contagious bovine pleuro-pneumonia, which was eradicated in 1898. Sheep pox has been absent since 1850. Glanders, which was outstanding as the main disease of horses, particularly where many horses were kept, at a time when industry and agriculture were so dependent on the horse, has not been confirmed since 1928. Epizootic lymphangitis was introduced in 1902 and eradicated in 1906.

These diseases were eradicated by a policy which depended on slaughter of the affected animals and their contacts and on sanitary measures and control of movements.

In addition, rabies has been successfully conquered and has not been present in the country since 1922. This disease is found all over the world. In many countries it is difficult to control, mainly because infection may maintain itself in wild carnivores from which it reaches domestic animals, notably dogs, and may spread rapidly over considerable areas. Useful vaccines are available and give promise of better control where they are properly used.

Two notifiable parasitic diseases may be said to have been eradicated. Parasitic mange of horses has not been in evidence since 1948 and sheep scab has been absent from Scotland since 1941, and from England and Wales since 1952. These diseases have been dealt with by treatment or dipping of affected animals and their contacts and by careful control of movements of animals which may have had contact with infested stock. Modern sheep dips containing gammexane have made a great contribution to the eradication of sheep scab by destroying the acari hatching from eggs. With earlier dips it was essential to carry out a second treatment after 7 to 14 days in order to deal effectively with freshly hatched parasites.

The notifiable diseases which are still encountered in Great Britain are anthrax, foot-and-mouth disease, swine fever, bovine tuberculosis and fowl pest. Bovine tuberculosis is enzootic, while the other four appear from time to time, usually because infection is brought into the country with essential imports and occasionally by other means.

Considerable care must be exercised in preventing the importation of all these diseases and others which have never been found in Great Britain.

The greatest risk lies in importing infected stock, and very stringent safeguards are in force to prevent introduction of infection by this means. Stock from sources which enjoy the same freedom from disease as Great Britain (Ireland, Channel Isles, Isle of Man, Canada) may be imported only at specified landing places where they are carefully examined and marked for identification purposes. They are moved from these ports on the authority of a licence which prevents their indiscriminate movement through a succession of markets and requires that they be detained at their destination for six days. Pedigree stock from Commonwealth countries may also be imported under conditions which may require the production of certificates of health or quarantine according to the disease position in the country of origin. Animals from other countries are allowed in only under exceptional circumstances which clearly show that the stock will make an important contribution to general livestock improvement. Sometimes the disease risk is so great that it may outweigh any benefit which the imports would confer by way of livestock improvement. For those that are imported meticulous tests, declaration of freedom from disease in a locality, and quarantine requirements are laid down to prevent introduction of infection. No notifiable disease has been brought to the country by livestock since these precautions were adopted.

Dogs and cats may be imported from any country provided they undergo quarantine at approved kennels for a period of six months. This has provided an adequate safeguard against rabies but the disease has been found on 23 occasions since 1924 (9 since 1945) in animals undergoing quarantine. In 1918 rabies

was introduced by a dog landed illegally and it was not until 1922 that the outbreak was finally brought under control.

The importation of live poultry and hatching eggs is prohibited except from countries where fowl pest is not present.

Besides the risks of infection from imported livestock, considerable importance is attached to the danger of infection being conveyed by meat and animal products and by a variety of goods conveying infection mechanically. It is well known that meat may contain the viruses of foot-and-mouth disease and swine fever. It is not possible to obtain all the necessary supplies from safe sources. Where meat must be brought from countries where such diseases exist every possible precaution is taken by making agreements with the governments concerned that only healthy stock, slaughtered in certain abattoirs, is used for export. In addition, it is required that waste material used to feed animals shall be boiled for an hour before it is brought into contact with stock. Nevertheless, imperfectly treated swill fed to pigs is probably the main source of infection with foot-and-mouth disease and swine fever. Control is also exercised over a variety of other imported material such as meat wrappings, sera and glandular products, hay and straw. Anthrax infection may be conveyed in imported bones or bone meal and also in imported vegetable feeding-stuffs. In most cases it is impracticable to have such material sterilised and the livestock population of this country cannot at present be maintained without imported feeding-stuffs. A certain amount of risk must therefore be accepted.

Anthrax

This is essentially a tropical disease. It does not spread to any extent in this country, as is indicated by the number of animals involved in each outbreak (1·07 cattle and 1·2 pigs in 1952). Control is exercised by careful disposal of the infected carcase, either by burial or burning, and disinfection of the part of the premises which may have been contaminated. Until this has been done movements of stock to and from the farm are prohibited. There are one or two areas in the country where anthrax is enzootic, notably when pastures are flooded by streams carrying tannery effluent. In such areas vaccination is practised with advantage. The general incidence of anthrax is subject to considerable fluctuation ; it was low during both wars when imports of feeding-stuffs and fertilisers were severely restricted but has since risen. Last year there were more cases of anthrax than in any previous year. A notable feature was the exceptionally high incidence among pigs—this is due to infected consignments of imported materials, but it has been impossible to incriminate any particular ingredient of compound foods or any particular consignment.

Foot-and-Mouth Disease

Infection is invariably imported from abroad. There was at one time considerable traffic in livestock between Europe and Great Britain and infection was frequently introduced by these animals. This trade came to an end by an Order made in 1892. When infection reached the Argentine in 1899 the trade in livestock with that country was also stopped. After traffic in livestock had ceased there were heavy imports of freshly killed meat from Europe and this trade was suppressed by Order in 1926. About this time refrigeration was developing and it became possible to carry carcases over long distances. It was in 1926 that the Foot-and-Mouth Disease Research Committee established that the virus of foot-and-mouth disease could survive in frozen carcases for long periods, at least up to 2½ months, and it became evident that serious risks were involved by allowing susceptible animals access to garbage or swill containing waste meat from imported chilled carcases. Unfortunately the importation of these carcases must continue so long as Great Britain is not self-supporting in meat, and it is now obligatory for farmers to ensure that swill is boiled for one hour before stock are allowed to come in contact with it. In spite of this precaution it is estimated that some three-quarters of the primary outbreaks in Great Britain arise from this source. Some progress has been made in establishing central boiling plants for the processing of swill and no infection has arisen from centrally processed swill. It

is along these lines that progress must be made to answer this particular problem. Infection has also occasionally reached Great Britain in other materials, and to reduce the risks import regulations have been brought into force as the need arose.

We have no record of cases arising from infection conveyed by the movement of persons or vehicles from abroad. Invasion of Great Britain by the virus of foot-and-mouth disease occurs when there is a heavy weight of infection in the Continent of Europe. There is good circumstantial evidence that birds on migration can and do introduce infection from Europe. Two members of the staff of the Animal Health Division who studied the problem concluded :—

> 'We have endeavoured to assess impartially the various factors having a bearing on the theory that birds on migration have been responsible for the introduction of foot-and-mouth disease into Britain. The seasonal incidence and location of primary outbreaks in the east and south coastal counties of this country shows a striking parallel to the period of autumn migration of birds and their area of landfall. We conclude that available evidence is adequate to establish a prima facie case against birds, and especially starlings on migration, as a means whereby foot-and-mouth disease is introduced into Britain; further that the frequency of its introduction is dependent on the extent of the disease in certain coastal areas of the Low Countries and north-east France at the season of bird migration.'

This is unfortunately a hazard against which no adequate precaution can possibly be taken. It can only be resolved by better control of the disease in Europe.

Foot-and-mouth disease has always been eradicated on every occasion when infection has been established in stock in Great Britain. This has been effected by slaughter of infected and contact animals and strict control of movements of stock. No movement of stock or material from the infected place is allowed and after slaughter and burial there is meticulous cleaning and disinfection of the premises. The infected place is quarantined for six weeks from slaughter or four weeks after disinfection is completed. When an outbreak is confirmed an infected area is declared around an outbreak, and movement of stock out of this area, about 15 miles radius around the infected place, is prohibited ; movement into and within the area is controlled by licence and confined to essential movements. This allows for examination of stock close to the outbreak and prevents further spread of infection. On occasion, if serious spread is threatened, as by infection having passed through a market, movement control is imposed over a much wider area so that dangerous stock may be examined and further multiplication of dangerous contacts prevented.

This system of control depends on the early reporting of suspected cases. The farming community is generally most co-operative and it is only rarely that disease exists for more than a day or two without notification. The fact that no vaccinated or recovered animals are present in the country allows frank lesions of disease to develop which are readily suspected by the farmer and recognised as foot-and-mouth disease by the veterinary surgeon. It is certain that without rigid control, the disease would cover the country within a very short time of its introduction because normal stock movements take place from one end of the country to the other and the major livestock markets distribute their animals over wide areas. Every time virus reaches the country this potential danger occurs. Since the present policy was adopted in 1892 there have been no outbreaks comparable to those of earlier days such as in 1871–72 when 52,000 outbreaks occurred involving about 3,000,000 animals. From 1892 to 1922 there were never more than 95 outbreaks in any one year. In 1922–24 a serious epizootic occurred and there were 1,140, 1,929 and 1,440 outbreaks in each of these years ; in 1942 there were 670 outbreaks and in 1952 there were 495. The number of outbreaks in the 31 years, 1922–52, was 8,427, an average of 272 each year.

Under conditions in this country where farmers are co-operative and disease is discovered early, and where an organisation exists capable of the extremely quick

action required to deal with this rapidly spreading disease, there is no doubt that the method used is the one of choice if the disease is not to become endemic, with all the serious effects on livestock which that entails.

Swine Fever

This is another virus disease which has had a varying incidence in this country. It has unquestionably been introduced from time to time by infected pig meats reaching pigs in swill. The system of control does not involve slaughter of infected animals, but consists mainly in quarantine of infected places and control of movement of contacts. When imports of dangerous materials were very low the disease was practically non-existent, but it has again become established in this country and in late 1952 and early 1953 a very serious outbreak was encountered. Movements of pigs, particularly in the hands of dealers and through markets, are the main agent in spreading infection and when movement controls are in force the disease is fairly rapidly mastered. In addition, infection is maintained by farmers selling for slaughter animals in the incubative stage of the disease, which in turn infect swill.

A useful vaccine is available. It has been found extremely difficult to persuade farmers to use it while disease is at a low level in the country, whereas its use becomes much more popular when numerous outbreaks are being experienced. A scheme to encourage its use in breeding stock is under discussion at present.[1]

Fowl Pest (Newcastle Disease and Fowl Plague)

Two isolated outbreaks of Newcastle disease occurred in 1926 and 1933. In 1947 infection was reintroduced with imported poultry carcases and has not yet been completely eradicated. The system followed is to slaughter infected and contact birds. This system has succeeded in eliminating the acute form of the disease on every occasion when it has appeared but a subacute form has been encountered which is less amenable to this system of control. In the first place, it is not so readily suspected by the farmer although reporting has, on the whole, been good; secondly, it is apparently more easily spread than the acute form. It is, however, felt that the only method which will prevent the establishment of this infection is to pursue the slaughter policy vigorously. Vaccines have been developed and are used in many countries where the disease is widespread or where it had been allowed to establish itself for many months before steps were taken to control it. The vaccine is effective up to a point but it has the serious drawback that in practice its use appears to enhance the effects of intercurrent infections and that when immunity is waning a natural infection will not be apparent but will render the bird infective.

Bovine Tuberculosis

Since 1925 there has been authority under the Tuberculosis Order to slaughter cattle affected with certain forms of tuberculosis. This is essentially a public health measure designed to reduce infection in milk. The animals which may be dealt with are those giving tuberculous milk or affected with tuberculosis of the udder, those with a chronic cough and showing other clinical evidence of tuberculosis, those suffering from tuberculous emaciation, and those excreting or voiding tubercle bacilli. A great deal of effort has been expended in carrying out the duties concerned with this Order. Farmers and veterinary surgeons report cases, but many are discovered in the course of routine clinical examination of dairy herds.

In 1936 the highest number of cases were dealt with—23,716. This figure has fallen steadily since then, and in 1952 only 2,831 animals were slaughtered.

Since 1950 valuable incentives have been given to farmers to encourage eradication of the disease, for 2*d.* per gallon of milk or £2 per head of stock is paid as a bonus for each of the first four years after disease has been eliminated from a herd and half that amount for a further two years. This is a direct outcome of the scheme which was introduced in 1935 in an effort to eradicate bovine tuberculosis—the Tuberculosis (Attested Herds) Scheme.

[1] Swine Fever—Registered Vaccinated Herds Scheme introduced on December 15, 1953.

Under this Scheme herds free of tuberculosis are established by the turbeculin test and a sizable number have been gradually built up until over 100,000 such herds existed at the end of March 1953. These comprise some 3,855,738 cattle and represent 41·4 per cent. of the total stock.

This is very satisfactory, for the incidence of the disease was at one time high. It was estimated in 1931 that some 40 per cent. of cows would react to tuberculin, which probably represented an overall incidence of at least 20 per cent. reactors.

Since 1950 an Area Eradication Plan has been in operation. Under this plan an area is selected and a further incentive to eradication on a voluntary basis is given by providing free tuberculin testing for all herds in the area. Free testing is available for a stated period, usually about two years. The herds which are cleaned under voluntary co-operation may become attested and thereby qualify for the available bonuses. At this stage the area becomes an Eradication Area and compulsory testing is carried out, reactors are slaughtered, and when all the herds reach the required standard of freedom the area becomes an Attested Area.

There are already four Attested Areas which contain over 700,000 cattle—Shetland, several counties in S.W. Scotland and S.W. Wales, and the Scilly Isles. Free-testing is proceeding in other areas in England, Scotland and Wales containing some 1,000,000 cattle. Part of these areas containing over 425,000 cattle will be declared Eradication Areas in January 1954 and the remainder a year later.

The intention is gradually to eliminate infection entirely and there is already evidence that other districts are almost ready to become free-testing areas. As eradication proceeds so many tuberculosis-free animals become available as replacement cattle that eradication is much more rapid because the herd owner whose herd is heavily infected can replace his reacting stock very rapidly by purchase of tubercle-free animals and many owners have replaced their whole herd with success.

Contagious Abortion

This disease has caused serious losses, particularly in dairy herds, over many years. Attempts have been made to establish herds free of infection as judged by the blood agglutination test. In some countries this system is the foundation of the scheme of control. In Great Britain this method has not found favour because it was found extremely difficult to maintain freedom from infection on account of the high incidence of the disease and the many possible means of introducing infection into a clean herd. When infection is introduced to such a herd the incidence of abortion is usually extremely high. The method recommended in this country is the use of S. 19 vaccine. This vaccine is capable of protecting the individual animal against infection for a comparatively long period and of preventing any serious spread of infection in a vaccinated herd into which fresh infection is introduced. In order to encourage vaccination and to make it available at a reasonable fee in all classes of herds a scheme has been in force since 1944—the Calf Vaccination Scheme. Under this scheme young females from the age of four months to the time of first service may be vaccinated at a cost of 2*s*. per animal. This has succeeded in establishing a considerable degree of resistance to infection in a large number of herds and is sufficient to maintain freedom from abortions which arise from this infection in a herd which is well managed and where no serious risks are taken. If the farmer wishes to increase the resistance of his herd he may arrange privately with his veterinary surgeon to have adult stock vaccinated and to re-vaccinate those animals vaccinated as calves, probably after their first or second calf. This procedure is of special benefit in herds where purchases are made or where other precautions cannot be properly carried out.

Vaccination has brought contagious abortion largely under control. There are, however, other causes of abortion, notably infection with *Trichomonas foetus* and *Vibrio foetus*. Trichomoniasis is not difficult to control by treatment of infected females and breeding rest for a period. The infected bull must be discarded. It is of interest that in an area of small farms where a communal bull was used, the adoption of artificial insemination brought a serious outbreak of this disease under

complete control. Artificial insemination is also the best weapon in controlling *V. foetus* infection, which is a venereal disease. It is obvious that while artificial insemination may be of value if healthy bulls are used, it is equally a potent way of spreading infection unless the bulls are healthy. An important duty of the Animal Health Division in recent years has been the examination of bulls which are used in Artificial Insemination Centres.

Another scheme in which the veterinary staff play an important part is in dealing with the disease aspect of the poultry stock improvement plan. Routine blood tests for pullorum disease are carried out, post-mortem examinations of birds from accredited flocks are made and general supervision of the disease in these flocks is exercised.

Laboratory facilities are available at two main centres, Weybridge and Lasswade. At Weybridge diagnoses of notifiable diseases other than foot-and-mouth are made. Confirmation of foot-and-mouth disease and typing of the virus involved is done at the Virus Research Institute, Pirbright. In addition to the main laboratories each division (virtually each county) has a small laboratory where microscopical examinations of various materials may be made by the field staff. Veterinary investigation officers have more extensive facilities and they assist, as do the central laboratories, with diagnosis of disease conditions other than the notifiable diseases and by carrying out biological tests for tuberculosis, etc. The laboratories play a large part in carrying out research work, not only on a long term basis, but on current problems which may arise from the field and may come through V.I.O.s who are in close touch with veterinary surgeons in their areas. The V.I.O. is responsible for investigation of local problems and may be asked by the central laboratory to carry out field experiments to assist with its problems.

In recent years the laboratories have played a large part in carrying out important research work having a close effect on the work done in the field in such matters as the efficiency of tuberculin (all the tuberculin used under the Attested Herds Scheme is produced at the Ministry's Laboratory at Weybridge) and S. 19 vaccine; the diagnosis of swine fever; the source of anthrax infection; studies in *V. foetus* infection and infertility; and the study of Newcastle disease and the efficiency of a vaccine against it. In addition, they have been concerned with researches on mastitis which have greatly contributed to the control of that disease, although not incorporated in any official scheme.

A great volume of research work is also done at other research institutes which are State-aided and their contributions have provided means of controlling many animal diseases which have not been mentioned in this paper.

The Influence of Parasitic Disease on Our Animal Production

by

Dr. E. L. Taylor

It may sound like an excerpt from political propaganda to state that half of the living creation is parasitic on the other half, nevertheless it is a biological truth. It may be still more surprising to some to learn of the biological view that even the species of parasites are more numerous than the species of animal creatures on which they live. The parasitic mites, the ticks, the lice, the fleas, the microscopic creatures called protozoa and the worms are a varied and a horrifying or interesting crowd, depending upon one's point of view. In Great Britain the group most troublesome to our farm livestock are the worms; among these the worst of all are the parasitic nematodes, and most of my examples will be taken from this group.

These round worms are very common parasites of the animals of the world. Their species are very numerous and in some countries they are still extremely prevalent among the human population. An American parasitologist, Stoll, who had a taste for figures and who worked for two years in China, calculated that the weight of the eggs of the common roundworm of man, *Ascaris lumbricoides*, voided by infected human beings in that densely populated country amounts to some 18,000 tons per annum!

Such a figure conveys some impression of the prevalence of these creatures before the introduction of strict hygiene. That our human population is now practically free from *Ascaris lumbricoides* is to be attributed not to any wonderful development of parasiticidal drugs nor to measures of control based on an understanding of complicated life histories, but merely to the strict adherence to a more or less perfect system of waterborne sanitation and sewage disposal.

Where our grazing animals, whose food is eaten off the very same ground on which they defaecate, are concerned, the complete avoidance of faecal contamination is quite out of the question and it becomes necessary to make a careful study of the relationships between the parasites and their hosts in order to discover anything that may help us to bring them under control, and also to gauge how much effort it will pay us to put into this endeavour. In other words, it is necessary to understand the influence of parasitic diseases on our animal production.

To do this it is necessary to know something of the background and so my contribution takes the form of a story which begins at the time of Adam and Eve and is projected into that happy future where world population is balanced by food output, and even if we are not at all happy, we have as much meat as we want.

The Primitive Period

Some little time ago, in endeavouring to express a conception of the primitive adaptation of parasites to their hosts I drew a picture of a Garden of Eden, in which all creatures lived happily together. The nitrifying organism, helped the plants to grow ; the bees helped the flowers with their fertilisation and were so happy in fact that they did not mind a parasite or two. And for their part the parasites were kind and their adjustments to their hosts so nicely arranged that little hindrance arose and even the sheep and their parasitic worms were all happy together in a community that had the guiding principle of 'live and let live.'

This is doubtless a little exaggerated, but my caricature is not so overdrawn as might at first appear and before we can understand the present position of parasitic diseases among our domestic animals it is necessary to realise that disease production is contrary to successful parasitism. For a parasite to injure its host may be regarded as an immoral act from the parasite's point of view, as any trend towards the extinction of the host community is also a threat to that of the parasite.

To keep our illustration of happy worms in happy sheep we must suppose that the primitive conditions provided plenty of room so that the sheep fouled the pristine pastures only to a small degree and the larval nematodes which they acquired were insufficient to cause any dysfunction in their internal mechanism and disturb the even tenor of the blissful days. Nor would the need for space requirements be very great, since the infected host reacts very strongly to the presence of the parasite and is able to do a very great deal in preventing the growth of too great a population. The adjustment mechanisms are extremely complex and as yet are but little understood, but they were in those primitive days and they still are adequate to enable the sheep to maintain its worm population at a level that is compatible with a state of health, providing it is given the opportunity of doing so.

Trial and Error Period

That is the primitive background. We may now proceed to the origin of disease, and keeping to our story we may suppose that man, with his partial knowledge of good and of evil, who was first a hunter and then a farmer, began to domesticate the animals and enrich the ground, to construct fences and, incidentally, to force the animals to eat the infested herbage. The worm population then went up with a jump and troubles began. This is the middle age of our history, an age of lack of understanding and of adaptation by trial and error.

Much could be recorded in this interesting chapter if time would allow. As with the more primitive part of the story recounted in the last chapter, much of the exact detail is buried in antiquity, so that we can only see some of the indications of the many trials and the many errors

that have resulted in our present-day grazing practices. Many of these, it is quite clear, have come about as an adjustment to parasitism and did not require any understanding on the part of the farmer. Still keeping to our illustration of worms in sheep, I might remind you that these, for the most part, are so small that only an expert who knows exactly what he is looking for can find them. The traditional farmer has, therefore, remained ignorant of their presence and during this period of trial and error has only observed that lambs thrive under certain grazing practices but fail to thrive under others. Quite a collection of shepherd's lore was accumulated in this way, often as a result of bitter experience, and enabled the farmer to steer a course of uncertain success without having any understanding at all. Some of this tradition is so ingrained in our make-up that we find it difficult to define our ideas—such for instance as is inherent in the conception of overcrowding.

The Age of Reason

Although the age of reason is supposed to have begun some time ago, its permeation into many of the affairs of man has been lamentably slow. One of these regions of retarded development has been in man's understanding of parasites. The process of research has only just begun and perhaps it is not surprising that we find the matter of parasitic disease much more complicated than we had thought. The work of classification and of the delineation of life-histories has progressed well and has enabled us to apply the direction of reason to the traditions of our fathers. Within the last few years, the research machine has really begun to develop. The age of realisation has begun. The research business is however an expensive one and we require to know something of expected returns in the amount of food that we shall have to eat. How much will it help us towards our increase of 60 per cent. by 1954 or 100 per cent. by 1964? What is the influence of parasitic disease on our animal production?

Before we can properly consider this point, there are certain hindrances of a psychological nature that must be met, and here I refer to the marked tendency for an emotional response to blind our judgment. It is necessary to make an approach in pure intelligence and to be critical and suspicious of any strong impression of dire and terrible loss that goes with tales of sudden death, or of the shootings and burnings that accompany outbreaks of certain epidemic disease. Foot-and-mouth disease hits the headlines of the newspapers and although it is of far less importance in this country from an economic point of view than are several of the parasitic diseases with which I am dealing, I have no doubt that a consensus of opinion among the audience of the most costly animal disease in Great Britain would show an overwhelming majority in favour of foot-and-mouth disease.

These dramatic incidents are by no means unknown in connection with parasitic diseases and a search through the literature reveals numerous records of sudden outbreaks of severe disease as, for example, in connection with the liver fluke which from time to time has caused very extensive loss. During the years 1879 to 1881 some three-and-a-half million sheep were lost in Great Britain. In 1950 there was a similarly acute but much less extensive epidemic in a part of Cornwall, in which some farmers lost 100 per cent. of their sheep. As recently as 1951 there was a striking outbreak of lungworm disease among cattle in the southern counties, in which there were numerous deaths, and many outbreaks in which between 50 per cent. and 100 per cent. of the milking cows were suddenly affected.

These and many other outbreaks of a sporadic nature are occurrences of obvious clinical disease such as immediately attract attention and are readily diagnosed by the veterinary practitioner, and often by the farmer himself. On that account the loss which they occasion is clearly felt, because it is unusual ; the tendency, however, is to regard these obvious occurrences as the only loss and to overlook what is taking place the whole time. That we tend to overlook what is there all the time is generally acknowledged, but we should realise that the recognition of loss from parasitic worms may be even more difficult than this, for it is impossible to

observe what loss is occasioned unless a comparison between worm-free and normal sheep can be arranged.

We have seen in the last chapter what the position was during the period of trial and error, the effects of parasites in producing obvious disease, and their influence on normal grazing practices. On that account alone we might suppose that their detrimental effect has been very great. It would seem however, as a result of recent observations made under controlled conditions, that their effect is even greater than we had thought.

There have recently been one or two revelations of a hidden loss where none had been suspected ; there was the one concerning yellow leaf stripe in oats, a disease which had been thought harmless until a chance trial of a new seed dressing led to the observation that many young oat plants were killed before reaching the surface of the ground. The hidden loss there had been very considerable. A more recent and even more interesting example concerned the feeding of penicillin to pigs and poultry which revealed that in certain environments some factor, presumably a bacterial organism, was depressing the rate of growth of what had been thought normal, healthy young creatures. Returning again to our example of parasitic gastro-enteritis in sheep, we now find the same kind of thing in operation. The normal is not the optimal. A colleague of mine at Weybridge, Mr. Gibson, has recently been carrying out a series of observations on twin lambs kept in two groups under identical conditions with the sole exception that one of each pair of twins was artificially infected with what was regarded as a moderate number of parasitic worms of a certain species and the other one left uninfected. Weights were taken at regular intervals and it was found that, although the infected lambs appeared to be normal healthy animals, to grow at the normal rate, and to be as fit and as happy as lambs should be, yet at the end of the summer their average weight was thirty pounds per head lighter than that of their twin brothers which were not infected with the worms. Furthermore this lost weight was never made up in spite of the worm infestation having been eradicated by the use of anthelmintic drugs, so that 30 pounds of meat per head had been lost for good.

It is always satisfactory to find confirmatory evidence for important observations and in this instance it was soon forthcoming from Dr. Spedding at the Grassland Research Station at Drayton, where work had been carried out to observe the possible effect of varying worm burdens on the rate of growth of lambs that were being used as a means of assessing the relative feeding merits of different swards. The results of these two independent series of observations so closely correspond that we now feel satisfied that a very ordinary infestation of stomach worms is sufficient to cause the loss of some 20 or 30 pounds of mutton per head. We have already seen that these worms occur wherever sheep are kept—it is indeed a wormy world as far as grazing animals are concerned and it seems there can be no doubt that the normal growth of our lambs is sub-optimal, and that through worm disease we lost some thousands of tons of mutton each year. If we liked to put a figure to it we might suppose a loss of, say, only 10 lbs. per head ; then among the four-and-a-half million lambs slaughtered in the course of twelve months the loss of meat would amount to more than 18,000 tons, for as has also been shown by Dr. Spedding, the proportion of offal to meat is greater in the wormy carcases.

We must conclude that the influence of parasitic disease upon our animal production at the present time is very markedly detrimental.

The Future Age of Eradication

During the period covered in the preceding chapter, in which I have dealt with the application of reason, there have been several remarkable developments in the use of new chemical substances for the destruction of parasites of many kinds—bacteria, protozoa, arthropods and worms. If we keep to our example of parasitic gastro-enteritis in sheep we have the example of phenothiazine, although in some ways it may be less remarkable than some of the antibiotic drugs in other fields. The point I wish to make, however, is that whereas with very few exceptions, eradication has seemed out of the question

and nowhere within sight, it now begins to appear on the horizon as at least a future possibility. We have recently seen the amazing eradication of malaria-carrying mosquitoes from Cyprus and from Sardinia. We are now daring to think that sheep scab has been eradicated from our country and there can be no doubt that as a result of the introduction of this same insecticide, benzene hexachloride, the sheep keds and sheep lice could be eradicated in the same way.

It would also seem at least a possibility, although not yet generally practicable, to eradicate some of the worm parasites. The late W. E. Swales demonstrated the practicability of using phenothiazine to eradicate the very harmful nodular worm from flocks of sheep in some regions of Canada where it had been a major cause of loss. In the colder parts of that country the spring pastures were found to be freed from the infective larvae of this worm, so that by treating the housed sheep before allowing them on to the pastures, the parasite was wiped out. This same parasiticidal drug is equally effective against the twisted wire worm of sheep, but the pastures are not so easily freed from the infective larvae, which would make the eradication seem impracticable for the present; nevertheless it can be envisaged as a possibility.

Some work that is being carried out by Dr. Spedding at the Grassland Research Station suggests that under the conditions of sheep farming on arable ground, it may be possible through the use of phenothiazine, together with a folding system, to free a flock from worms altogether and to keep it free. Even if this attempt succeeds under close scientific supervision it may be some time before it can be regarded as a practical procedure for the sheep farmer. Nevertheless it is a new beginning and there seems every reason to believe that the future will provide us with more and better parasiticides so that we may be able to eradicate one parasite after another and step up our animal production to a degree that is beyond our present expectations.

We may conclude that the effect of parasitic disease on animal production has increased since primitive times; that during a period of trial-and-error adaptation they caused very great loss and in no small measure governed the development of grazing practices; that the last thirty years of investigation have revealed some understanding of control and increased our appreciation of loss; that the past decade has intensified this to a marked degree, so that we now see it to be very great. The measure of control increases, however, and eradication of many parasites is now seen for the first time as a possibility for the future. We may therefore look forward to a very considerable advance in our production of meat and milk as the numerous parasitic diseases of our farm stock are brought under an increasing measure of control on the road to ultimate eradication.

Husbandry and its Influence on the Incidence of Disease in Animals

by

J. O. L. King

In agriculture to-day the cry is for greater production, and to meet this demand livestock are required to mature more rapidly and to yield more abundantly. Because their productive powers have been greatly increased, the animals kept on our farms at the present time differ from their wild ancestors. Wild cows produce enough milk to rear one calf; to-day many cows give ten times and some even twenty times this quantity in a lactation. Pigs whose wild forebears grew slowly and reared one litter a year are now required to fatten rapidly and rear twice the natural number of litters. A hen in the wild lays about forty eggs a year and broods them and rears the chicks herself; her domesticated descendants are expected to produce five times as many eggs, and broodiness has become a crime.

This increased production has been achieved by an acceleration of the rate at which the excretory, digestive, and circulatory organs function, which means that a higher standard of nutrition is required, and that domestic animals have a lowered resistance to, and must be protected from, inclement weather. For this reason they have to live a controlled existence, and can only consume the foods supplied to

them. Wild cows could eat the grasses they favoured, could shelter at will, and were suckled at intervals by their calves ; their descendants are tied in cow sheds with concrete floors, are required to eat large quantities of concentrated foods, and are milked by machine at regular times. Wild pigs root about in the earth and wallow in the mud and sleep in dry, warm, draught-proof dens which they burrow out for themselves in bushes or undergrowth, and which they always leave to void their dung and urine. To-day domesticated pigs are confined in piggeries, are often compelled to excrete close to their sleeping quarters, and are given no opportunities for rooting or wallowing. Hens used to run about freely, pecking at insects and dusting themselves, but may now be confined in deep-litter houses, or in battery cages with no opportunities for amusement, and may have to live on pelleted foods which give no variety from day to day. It is not possible to allow domesticated animals to return to their ancestral way of life, for many species would not survive and those that did would certainly not produce as required. They must be kept under those conditions which yield the most economic return, but they must be offered a way of life which they can travel safely.

The relationship between husbandry and disease is, in many cases, obvious. Underfeeding, or feeding improperly balanced rations, even if one of the specific mineral or vitamin deficiencies does not result, can make animals more susceptible to infectious or parasitic diseases. The genetic make-up of the animals can regulate the incidence of disease, for though some strains produce animals which will live and remain healthy under good, moderate, or even bad conditions, others produce individuals which will not live even under good conditions. Certain strains of pigs produce a number of piglets which are hermaphrodite or have a hernia or an imperforate anus, and a relatively high percentage of poultry in some flocks develop fowl paralysis or leucaemia or evert the cloaca when laying.

Environmental conditions can influence the incidence of disease, but because they are often associated with dietetic errors, and in many cases are secondary to them, there is a danger that their importance is not sufficiently realised. Few detailed surveys have been made showing the effect of husbandry on disease incidence, but Withers (1953) found that faulty methods of husbandry were largely responsible for the high mortality in calves. He found that climate was the chief extrinsic factor influencing calf mortality, and was probably responsible for the pronounced seasonal increases in the death rate of calves in the early spring months, which was more marked in Scotland than in England and Wales. The adverse effects of extreme cold, wide temperature ranges, and absence of sunshine combine to render the early months of the year very unfavourable for the survival of the young animal. Withers also found that the occurrence of unseasonable weather at other times of the year was likely to be responsible for sporadic rises in the death rate.

Although our winters may not be very severe when compared with those encountered in other parts of the world, they are long and provide the greatest environmental problem, particularly in the northern parts of the country. It is well known in veterinary practice that the incidence of disease in stock at the end of the winter period is greater than at any other season. Phillips (1946), by examining the records of a knackery in West Wales over a four-year period, found that the intake of cows rose to a far higher level in the spring months, in particular during April, than at any other time of the year. The average monthly figures show that during the major portion of the year the intake was approximately one a day, but that there was a rise to 54 in March and 63 in April, falling to 45 in May.

The breeding policies which have improved the productive capabilities of certain breeds have reduced their hardiness. Galloway and West Highland cattle are required to live on exposed hills, and the stamina which enables them to do this is linked with slow maturity. Aberdeen Angus cattle are noted for their early maturity, but must be housed and well fed if advantage is to be taken of this breed characteristic. Ewes of the mountain breeds kept on the hills have to survive a period from about September to March

during which they will be exposed to bad weather conditions and will suffer from a shortage of nutritious food. This period coincides with service and pregnancy, and the fact that they can rear about 85 lambs per 100 ewes, and live on the hills for four or more breeding seasons emphasises their stamina. The larger, more rapidly maturing down breeds with their softer, but higher quality, fleeces would not survive a winter under such conditions, but are far more productive on more sheltered farms.

It is also important that stock should be given time to become acclimatised to colder and more rigorous conditions than those to which they are accustomed. Many farmers prefer to 'go north' for stock replacements, and those buying stock from more sheltered farms than their own during the winter months realise that their purchases may require extra attention. Hill sheep farmers are having difficulties with rams which have been forced for sale. As lambs they are housed and heavily fed and get little exercise, but after purchase in the autumn they are turned out on bleak hills to serve the ewes, and are required to find their own food. They then lose condition and their lamb-getting powers are reduced, even if they do not die from exposure. Some poultry farmers with exposed farms find that stock cockerels bought in are unsatisfactory stock getters and rapidly lose condition when mated up, but that birds reared on the farm from eggs of the same strain prove successful.

The aim must be to create, under each system of farming, an environment which is as favourable as possible to the individual and which will allow it to produce the maximum amount of meat, milk, or eggs. At the same time the system should be unfavourable to the development and spread of disease. It is particularly important that this ideal should be achieved for young animals, for an animal which has been subjected to faulty feeding and management, or has suffered from disease in its youth, never thrives in the same way as one which has been healthy from the start.

In some areas young dairy breed heifers are kept unhoused all the year round, and for economic reasons they may have to be confined in exposed fields. During winter they may develop and appear to thrive, but there is always a danger that they will fail either to come into oestrus or to conceive when mated. When conditions improve in the spring the majority hold to service normally, but do not then calve in the autumn as required to produce winter milk.

Pigs will not tolerate damp and cold conditions, and rheumatic lamenesses and outbreaks of pneumonia are fostered by such surroundings. Many farmers keeping pigs in these circumstances have had severe losses. Even if symptoms do not proceed to these lengths, coughing and savaging and tail biting are quite likely to result, causing a reduction in the growth rate. During severe frosts the combs of undubbed stock cockerels, particularly Leghorns, may become frostbitten and this leads to infertility. Young fowls turned out from hovers in the cold weather in early spring will huddle together and indulge in cannibalism, pecking one another's tails and wings, and sometimes causing extensive injury and death.

To avoid these evils which result from exposure to winter conditions, animals have to be housed, but too little is known about the effects of housing on health. The influence of air temperature and the effects of humidity on bodily comfort and health are not fully understood and a great deal of uncertainty surrounds the general problem of ventilation and, in particular, the optimal air space allowances. In general the buildings provided to house cattle need not be elaborate, but they must be dry and well ventilated but free from draughts, and they should be capable of being thoroughly cleansed and disinfected. Some buildings are unnecessarily palatial —you may have heard of the nobleman who erected a magnificent set of farm buildings and who used to take his guests on a tour of inspection, and at the end of their visit would say, 'You must be tired after your walk; will you have a nice glass of milk or a glass of champagne? It makes no difference to me which you choose as they both cost me the same.'

It would appear that dairy cattle, even high-yielding cows, can be kept outdoors during winter to a far greater extent than is usually considered desirable, the limiting

factor generally being damage to fields by poaching rather than any harmful effect on the cattle. The poor bodily condition met in cattle at the end of the winter period is probably mainly due to the cumulative effects of a low plane of feeding for five or six months, but it is certainly aggravated by lack of exercise caused by the need for housing. The obscure digestive disturbances met in cattle which are tied up during winter may be as much a result of insufficient exercise as of faulty feeding. It is certainly true that bullocks tied in stalls for fattening develop digestive troubles more often than those fattened loose in yards. When cattle are released from a shippon after a long period of close confinement their gait is stiff and has lost the easy motion associated with normal health. If these animals are heavily pregnant, the accompanying lack of tone of the uterine wall and other muscles may well lead to difficult parturitions. Many farmers who keep their cows in covered or semi-covered yards during winter claim as a definite advantage of their system that the incidence of disease is low because the cows are kept healthy by continually breathing fresh air and having constant exercise. They claim that they have few barren cows, that the cows calve easily and that digestive and pulmonary disturbances are rare. Similarly, farmers who have experienced difficulty in rearing calves in calf-houses have had fewer losses when they have kept their calves from birth in open-fronted sheds.

In designing animal buildings attention should be paid to the provision of an efficient system of ventilation, which means the uninterrupted exchange of fresh for foul air. It is possible to use mechanical ventilating plants, but in most animal houses natural methods are employed, based on two natural phenomena. Firstly the air expired from an animal's body has a higher temperature than that inspired and so tends to rise. To a lesser extent the air round an animal's body becomes warmed and it also expands and rises. If provision is made, these warm gases will pass out and fresh air will enter to take their place. Secondly, even on a very calm day the air is not still and this movement drives air into a building through a suitable opening and dilutes and mixes with the air in the building and forces it out through openings on the other side. So a system of natural ventilation is composed of two parts—making provision for the escape of foul air through an outlet, and for the entrance of fresh air through an inlet.

If animals are kept confined in buildings to which fresh air is not admitted the air in the building tends to resemble expired air in composition, which means that the oxygen content is reduced and the carbon dioxide content and the humidity are increased. The oxygen decrease is of no practical significance. Although no symptoms occur due to the carbon dioxide increase it is possible that the raised concentrations will affect animals continually living in such an atmosphere. The excessive humidity prevents free respiratory loss of water. In addition, if in cold weather the inside surfaces of the walls are much cooler than the air of the building, water will condense on them. If the building has cavity walls the temperature of the inside of the walls will be far above that of the outer air, so that ventilation can be considerably restricted before condensation takes place, and the building will be warm, but not damp. But if poorly constructed houses are not freely ventilated in cold weather the condensed water dripping from the roofs and walls means sodden bedding and a wet environment. A considerable amount of dust is found in the air of animal quarters and this accumulates if it cannot pass out of the building. It consists mainly of particles of food, dried faeces, and cuticular debris, but micro-organisms are also present. Some of these may be pathogenic, and if a cow with tuberculosis of the lungs is housed in such a building the air soon becomes laden with tubercle bacilli which circulate to the other cows.

Animals kept continually in a warm, impure atmosphere feel the cold more when turned out, and may have a lowered vitality and a lessened resistance to disease. Respiratory diseases may be brought on if an animal is suddenly transferred from warm to cold surroundings, such as when a cow going dry during the winter period is turned out of an overheated shippon into an open yard, or is exposed for sale in a draughty market. The conditions under

which young calves are marketed in certain areas leaves much to be desired, for they are brought down from the warm calf houses on the farms where they are born and exposed in damp draughty pens. Is it any wonder that they often develop scours or pneumonia? In those cattle-rearing areas where the collective marketing of calves is necessary they should be housed during sale.

But in spite of these adverse effects of bad ventilation it is surprising what low standards can be tolerated by cattle without apparent harm being caused. However, it must be realised that these conditions are generally met on small farms where old buildings are still in use; since few animals are kept, they receive individual attention, and are usually turned out in the fresh air for exercise whenever the weather is suitable, and this appears to compensate for the disadvantage of bad housing.

It appears that with pigs the position is different. They thrive best, and remain freest from disease, if they are kept at a constant temperature, usually about 70° F. which should be achieved without greatly increasing the humidity of the atmosphere. Young piglets do better if even higher temperatures—about 80°F.—are available where they sleep, and this is generally achieved in indoor piggeries in cold weather by the use of artificial heat over the creep. This has the added advantage that the young pigs are encouraged to lie away from the sow, which reduces the risk of crushing. In the outdoor systems the creep may be covered with hay on the principle of a hay-box to retain the heat coming from the piglets' bodies.

For fattening pigs the system of housing generally known as the Belfast System, described by Shanks (1942) has proved satisfactory. The piggery is a long, low building consisting of a series of well insulated houses providing the sleeping quarters, so that the heat from the pigs' bodies is conserved. Yards are provided for each pen so that all excreta and urine are voided in them, and the drinking bowls are placed outside so as to prevent the humidity inside from rising. The pigs are fed inside on dry food only. In order to allow the pigs free access to the yards without excessive draughts, swing doors are provided and a concrete baffle wall is built inside the house opposite the door. Maximum and minimum thermometer readings recorded in one of these houses for a year showed that there were no sudden changes of temperature and the greatest day or night variation was 12° F.

In Danish piggeries with the dunging passage under the same roof as the sleeping quarters and the natural system of ventilation, the provision of cavity walls, low lined roofs and double windows helps to maintain an even temperature, but, unless the ventilation is controlled by adjustable inlets, such as hopper type windows, and ventilating bricks and effective extraction cowls, warmth is achieved at the expense of a high humidity. In some piggeries where all means of ventilation have been closed to raise the temperature, the ammonia in the atmosphere may bring tears to the eyes of any who enter. Such conditions predispose to pneumonia and coughing. Farmers using the Danish system who have fitted extraction fans over the dunging passages to remove the excessive humidity and ammonia and have fitted thermostatically controlled heaters over the sleeping quarters have achieved far better results, and consider that the greater well-being of the pigs more than pays for the electricity consumed.

Grouping the intensive systems of poultry keeping together, faulty ventilation is the chief error in management, and it is amazing how many farmers planning intensive houses forget about the necessity for adequate ventilation. Colds are more prevalent in birds kept in badly ventilated houses, and with adult poultry it is best to over-ventilate. Chicks, however, unlike adult birds, do well in stuffy conditions for they are very susceptible to draughts, chilling being a common cause of death.

To obtain a balanced agricultural output means should be found to reduce the losses which may occur in cold weather. Growth in young stock must be uninterrupted and bodily condition in adult stock must be maintained during the winter. On many farms to-day young cattle develop little during the winter months, and growth occurs only during the summer,

and many milking cows steadily lose condition throughout the period of winter housing. These undesirable features are mainly due to a low plane of feeding for five or six months, and a great deal more attention must be paid to the winter nutrition of farm stock, but improved methods of housing and management can also play a part in bringing about an improvement, for stock given insufficient protection from exposure use energy for the maintenance of body heat, which would otherwise be available for production. With any class of livestock the aim of good husbandry should be to obtain the maximum production possible from a particular individual and this can only be achieved if the method of husbandry employed is satisfactory.

References

Phillips, R. (1946) : *Agriculture*, **53**, 246.
Shanks, P. L. (1942) : *Vet. Rec.* **54**, 233.
Withers, F. W. (1953) : *Brit. vet. J.* **109**, 122.

ANTHROPOLOGY AND INDUSTRIAL RESEARCH[1]

by

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THIS is a short paper, and I have to deal with a very broad subject. I must therefore be selective. I am not an anthropologist but an industrial sociologist by training, and, since I must assume that anthropologists will know less of my subject than of their own, I propose to concentrate in the first place on the approach and methods of industrial sociology in this country. Then I will endeavour to point up some broad similarities and contrasts with the work of the anthropologist. In this way I hope to show what industrial sociology has gained from anthropology, and in turn, the directions in which the industrial sociologist has deemed it desirable or necessary to modify or develop the anthropologist's tools.

INDUSTRIAL SOCIOLOGY

Most sociological studies undertaken in our society could properly be regarded as studies in industrial sociology, since we live in a society which is dominated by industrial institutions, and, as good anthropologists, we must expect to find a close relation between industrial and other institutions. Thus many community studies, or studies of, for example, class or family structure, are relevant to an understanding of behaviour at work.

I propose, however, to confine my discussion to research which has sought to throw light on the behaviour of people at work by studying, at least in the first place, the social system of the workplace. This is merely to recognise time limitations and the fact that most of the work which is regarded as industrial sociology has accepted this limitation of the field of study. As the subject develops, however, the necessity for a closer link between study of the workplace and of its context in community and society will be increasingly recognised.

[1] Paper read to Section H (Anthropology and Archaeology at Liverpool on September 7, 1953.

RESEARCH PROBLEMS OF THE INDUSTRIAL SOCIOLOGIST

The industrial sociologist, like the anthropologist, has (i) to enter his chosen field of study and become accepted by the people amongst whom he proposes to work; (ii) to have some theoretical concepts to guide his selection of data and to provide a framework for the presentation of his conclusions; and (iii) to devise methods for collecting the information which he seeks.

ENTERING THE FIELD AND ESTABLISHING A RESEARCH ROLE

A factory is more difficult to 'enter' and 'live in' than a community, for the workplace is a fairly exclusive social unit. The traditional philosophy of *laissez-faire* competition has meant that many firms have sought to keep their affairs secret, and has led them to resent intrusion. Moreover, workers in modern industry are literate, educated and fairly sophisticated and, because of the nature of economic and technical organisation in our society, they are organised in interest groups which are anxious to see the democratic rights which have been achieved in the political sphere recognised also in industry. Varying degrees of inter-group tension are therefore encountered among them.

In these circumstances, both management and employees tend to be very sensitive about research. Higher management fear that 'latent problems will be brought to the surface,' as they often put it; indeed, the sort of reception which

research proposals get from the management of a firm is probably a very reliable guide to the state of relationships in the organisation; the worse they are, the more hostile is the reaction to the researcher. This probably explains why most sociological research in industry in this country has been done in firms which enjoy a reputation as 'good employers.'

Employees also are often suspicious of research proposals. Like other people, they tend to perceive the researcher in terms of their own prior experience, and the activities of time and motion study engineers and industrial psychologists have not always provided the happiest of precedents for them. They are likely therefore to perceive research as management-inspired and not to their benefit. Their Trade Unions I have found fairly co-operative, principally I think because they have considered that the conclusions of independent sociological research would reflect upon management rather than upon themselves. The industrial sociologist will, however, have to pay more attention to his relations with Trade Unions in the future, for it is now recognised that study of the associated Trade Unions is essential to an understanding of the social system of the factory itself, and that there are problems of Trade Union structure and organisation which merit study in their own right. There is unfortunately evidence that publication of Goldstein's *British Trade Unions*, which was in fact a study only of certain restricted aspects of the Transport and General Workers' Union, has led to a certain hardening of the attitude of Trade Union bodies towards this type of research.

The problem of gaining entry to the field is further complicated by the novelty of sociological research in industry. It has developed in this country only during the last decade or so, and accordingly has no established meaning or role for industrialists and their employees.

If, however, initial soundings are successful in preparing the ground, a formal approach can then be made to the controlling body of the organisation. Although it is of course essential to secure the approval of directors or senior management first, it is important to stress at this stage that sanction will have to be obtained from the leaders of all other important sub-groups in the organisation before research work as such can be started. This process must commence as soon as official approval is forthcoming from top management, for it is important to avoid the spread of rumours that the research has been initiated by the firm. Since, as I said earlier, workers in industry are very conscious of their rights, and have established machinery for consultation on matters affecting them, sanctioning of the research by the leaders of all 'sides' can only be achieved if the researcher seeks to promote understanding and approval of his intentions. Dissimulation, even if temporarily successful, is likely to prove disastrous as the research develops. The researcher must put his cards on the table, and must explain fully his purposes and the methods he proposes to use. He must, that is, establish a collaborative relationship with the leaders of the various groups in the organisation, and must maintain this relationship as his work develops. Likewise, once the initial sanctioning of the research has been effected, the researcher must continue the process of securing understanding and approval of his work, as his research as such gets under way, and comes to involve an increasing number of people throughout the firm. Yet whilst he must become accepted by all parties, and maintain this acceptance, it is essential that he avoids becoming identified with any of them. Should he allow it even to appear that he is allying himself with a particular subgroup, there is a danger that his relations with others will deteriorate, that their willingness to furnish information will diminish, and that his report will be rejected and even suppressed by other parties.

In the light of the difficulties which face the would-be sociological researcher in industry, and of the high degree of social skill which is required to establish and maintain a research role, it is not surprising that co-operation for research purposes has so far been achieved with only a relatively small number of firms. In present conditions I think that University staff enjoy certain advantages. The Universities have a tradition of independence, and command respect in all

sections of the community. This makes it easier for the University sociologist to obtain research facilities in industry, and to preserve an independent status whilst he is involved in the work.

Many other issues arise in connection with establishing and maintaining a research role. The problems associated with presenting a report and securing clearance for it, and with ' getting out ' of the research field, are often as exacting as the problems of ' getting in ' and ' staying in.' Time permits me to deal only with one other general consideration which is relevant to each of these stages. We still hear much of the controversy between advocates of ' pure ' and ' operational ' or ' problem-centred ' research ; it is an important issue, and I do not doubt that each has proved its worth in particular fields of scientific endeavour. All scientists, however, have to adjust to the conditions imposed by their social *milieu*, and the industrial sociologist is no exception. Whereas the anthropologist, if he is so inclined, can try to regard his primitive society as a museum piece, as it were, this is seldom possible for the industrial sociologist. Contrary to popular belief, a workplace is in a constant state of flux or change, and people at all levels in industry tend to be ' action-' or ' problem-oriented.' They are interested in getting things done, and in grappling with the problems which action presents. They are unimpressed by the pursuit of knowledge for its own sake—at least as a full-time occupation—and research which seems likely to make a contribution to action in the not-too-distant future is therefore more acceptable to them. If it be a contribution to the solution of their own problems, so much the better. Moreover, we live in a society in which the rate of change is unprecedented, yet in which a singular development of social conscience is leading increasingly to a demand that change shall be controlled in the interests of human welfare. In these circumstances it has been inevitable—and many would add, desirable—that most sociological research in industry has been ' problem-centred '—that is, it has been designed to throw light on matters which are a cause of concern to people in our society, and thus to enable these problems to be tackled more effectively. I would not deny that this has brought disadvantages—it has, I think, resulted in quite a lot of superficial work of both limited theoretical and practical value—but on the whole it is a healthy and desirable development. It certainly makes it easier to achieve research facilities in industry, and thus to establish the industrial sociologist's role—which is essential if any other type of research is to develop anyway. ' Problem-centred ' research is also more congenial to most industrial sociologists, for whilst, like the anthropologist, they are studying a social system from the ' outside,' they are also, unlike the anthropologist at work in a pre-literate society, sharers in the value system of the wider society of which the industrial institution is a part, and they are also compelled (as will be pointed out later) to analyse this institution in terms of its relationships with the wider society. They do, therefore, to a certain extent at least, share in the concerns and anxieties which agitate others in their society, and accordingly are happier when they feel that they are making some contribution to their resolution. I conclude, then, that we should not seek to withdraw into ' pure ' industrial research—but should seek rather to improve the quality of our ' problem-centred ' work. We must aim to study problem areas in a more fundamental way. We shall thus not only enhance our practical contribution, for work which is theoretically more sound will provide a surer basis for action ; I would also suggest that work of this nature may in the long run make a more fruitful contribution to the theoretical development of our subject than work of any other kind. For where people are aware of problems, social change is usually occurring or is imminent, and change provides us with ' natural experiments,' the careful observation of which can lead to the validation or refinement of concepts which we have derived from the study of more static conditions.

This preoccupation with problem areas, however, increases the responsibility of the researcher and makes greater demands on his skill. At the outset of his work, whilst emphasising that his primary function is to extend knowledge, he must

point out that a report will be made available to his collaborators, and indeed must be approved by them before being published, and that the results of his work may be of value to them when changes are being considered in the future. During the course of his research he must resist the frequent demands for advice and for the disclosure of information which will be made. When his work is completed, however, or as particular stages are completed, he must 'feed back' his conclusions in a form which makes them intelligible to the people amongst whom he has been working. This is seldom an easy task for the person who is accustomed to use technical jargon, and sociologists have still much to learn if they are to achieve an accepted role in industry. At this stage, too, the industrial sociologist must be careful to avoid over-involvement. Otherwise, his erstwhile informants may become too dependent on him and he may find it virtually impossible to 'get out' of the situation, and his independence as a researcher may be jeopardised. The solution, I believe, although it requires considerable skill to achieve, is for the sociologist to confine his involvement to ensuring that his conclusions are understood. He should, that is, act only as a clarifier or interpreter of his report, and should ensure that the persons themselves decide what action, if any, is to be taken on the basis of it.

Analytical Concepts

Industrial sociology has tended to develop outside the main stream of thought in sociology, and likewise general sociology has tended in the past to ignore behaviour within industry.

There are therefore few concepts which find general acceptance as yet, and the few that do tend to be catchwords, which are honoured in name and have different meanings for different people.

Therefore, whilst I shall attempt to generalise about the very limited amount of sociological research which has been done in industry in this country, it must be appreciated that I have time to deal only with a few of the broader concepts, and that my perception of these will be coloured by the experience of my colleagues and myself at Liverpool.

The industrial sociologist studies the workplace as a *social system*, that is, as a system of inter-related and inter-dependent *groups*. The manifest purpose of the workplace is to provide goods and services, and top management initiates and seeks to maintain a *formal organisation*, based on the principles of division of labour and a hierarchical system of authority and responsibility, for the achievement of this end. Barnard has defined formal organisation as, 'A system of consciously co-ordinated activities of two or more persons' (1). It does not take into account particular social situations or the personalities of specific members of the organisation; it is impersonal—a system of prescribed, ideal relationships. Formal organisation normally defines the managerial 'line' organisation, the functional or 'staff' organisation, the relations between 'line' and 'staff', and may prescribe disputes procedures and even the allocation of job responsibilities amongst rank and file employees. It is always to a large extent explicit, and may be embodied in organisation charts, handbooks, and so forth. The industrial sociologist seeks to describe the formal organisation, and then to see how it works in practice—in other words, how people do in fact behave—because it seldom operates as defined. In order to understand its operation, he must proceed to study the *interest groupings* and the *social organisation* of the workplace.

An interest group consists of a number of persons who perform a similar function, and who consider that they have an interest in common which is distinct from that of other groups. The time-worn distinction between 'management' and employees, of course, has significance in these terms, but these are very broad categories which allow of considerable refinement. Thus in recent decades there has been a growing cleavage between owners and managers; a feeling of independent group consciousness on the part of foremen has developed; and particular groupings amongst rank and file employees, such as office staff, craftsmen and process workers, have become more clearly defined. And so one could continue. These interest groupings can be regarded as the class organisation of

the workplace, and Trade Unions and the power structure of the factory develop on the basis of them. They are, however, broad categories, and the members of one of them will seldom constitute a group to the social psychologist, to whom the term implies, amongst other things, regular face-to-face interaction amongst the members, and an awareness on the part of each member of the others as individuals.

These social groups, as we should call them, tend to arise especially within interest groups but may overlap their boundaries, and knowledge of them is essential to an understanding of behaviour at work. The industrial sociologist proceeds therefore to study the social organisation of the workplace, as the network of these social groups is frequently called. Most managers and employees will normally be members of one or more of these groups, the groups themselves will tend to overlap, and some groups will be more highly structured and cohesive than others. Many will have a work basis, but others will be associated predominantly with recreation, eating, or residence. Thus within the category ' management ' the directors, top managers and departmental managers will normally be distinguishable as separate groups, there may be subgroups within each of these groups, and other groups may have members drawn from the ranks of both directors and top managers, or from both top managers and departmental managers ; foremen will tend to form groups amongst themselves, but some may be members of groups which include managers, and others of groups drawn mainly from employees ; then there are the multifarious work and other groups amongst employees themselves.

The industrial sociologist often calls this social organisation the *informal organisation*, in order to contrast it with the formal organisation. It is, as I have suggested, a distinction which is essential to the understanding of behaviour, and it also helps to throw light on the needs which people seek to satisfy through work. For whilst formal organisation is designed to achieve the economic ends of the organisation, informal social organisation arises in response to these individual needs. Since the solution of many of the major problems of our society involves a reconciliation of individual and social goals, the industrial sociologist has been drawn increasingly to the study of the individual in his group context. There have been a number of studies, for example, of the relations between individual satisfaction in work, group morale and efficiency. In this connection we have used the concept of *function*, which may be defined as the purpose which a group serves in relation to the organisation as a whole, and the needs which its members seek to satisfy through membership of it.

Many would regard this as an unwarranted trespass into the preserve of the social psychologist, but theoretical as well as practical considerations are now dictating a marriage of convenience, if not as yet a close working partnership. For if we seek to explain behaviour, we have to recognise the inter-dependence of social structure and personality. As Professor Simey has said, ' Changes in institutional structure and changes in the personalities of the individuals associated with them are inter-connected processes, and the problem of social change cannot be satisfactorily dealt with unless action is based on an understanding of the very complex ways in which they interact ' (2). A number of studies, for example, have stressed the desirability of consultation in industrial relationships. In my own work, ' consultative leadership,' as I called it, emerged as an important element in effective day-to-day relations, but the very limited ability of changes in formal organisation to promote this type of leadership was also apparent (3). It is of some value to describe the relationship that exists between a certain pattern of leader behaviour and certain desiderata such as high morale or efficiency, but this discovery cannot be validated unless we can say why leaders tend to behave as they do, and hence how we may endeavour to effect change in a desired direction. If we are to do this, we cannot ignore personality, for behaviour results from the interplay of personality and social environment. A recent study, for example, has shown that leader behaviour is related not only to the formal and informal social organisation of the workplace, but also to the general status attitude of the leader (4).

This, like other facets of personality, will have been influenced by family and class background, for example, amongst the many factors which operate outside of the social system of the factory itself.

The social system of the workplace, then, can be regarded as a system of ' wheels within wheels,' or of ' groups within groups,' and the whole operating within the wider framework of society. Just as the inter-dependence of the various segments of the social system of the workplace was belatedly recognised—at least we no longer think that supervisor-employee relations, for example, can be studied in the abstract, as Elton Mayo did —so the interdependence of workplace, community and society, neglected for so long by the industrial sociologist, is now regarded as important.

Methods of Collecting Information

As a first step, the industrial sociologist exhausts documentary sources. There has been a tendency to neglect these in the past, but the better studies now make full use of historical methods. Examination of records can be supplemented by free interviews with a small sample of long-service employees. Old records, of course, are not necessarily more reliable than old men, but they do provide valuable ' clues ' which can later be pursued more systematically, and are an additional source of information which is not available in pre-literate societies. The use of historical methods also enables the industrial sociologist to see social organisation as a developing process, and thus makes it easier for him to understand the dynamics of the existing situation. The cleavage between craftsmen and production workers, for example, which is often encountered in this country, can only be understood in terms of its deep historical roots.

For the collection of contemporary data, I think it is true to say that in general the industrial sociologist has been preoccupied with structured individual interviewing, usually with the aid of the questionnaire. This method has merits ; it is most appropriate for the collection of demographic and other data which is readily classifiable, and it facilitates the quantification of this sort of information. When excessive reliance is placed upon it, however, its use may entail the neglect of much significant data, and as regards social relations where an element of tension or conflict is present, it may not provide accurate information. The answers to questions such as, ' How do you get on with your foreman ? ' when asked in a highly-structured interview, are invariably noncommittal or equivocal. Recent research has accordingly sought to remedy the past neglect of non-directive techniques and direct observation in industrial research.

Non-directive methods are being used increasingly on a group as well as an individual interview basis as, for example, in the research into joint consultation undertaken by the Department of Social Science at Liverpool (3) and in the inquiry at the Glacier Metal Company carried out by the Tavistock Institute of Human Relations (5). Two tentative conclusions have been drawn from this limited use of the technique in industry ; in comparison with conventional methods, ' rapport ' is more readily established and maintained, and the quantity and quality of the information obtained about social relations is enhanced.

Although it is now appreciated that more direct observation of industrial behaviour could be made with advantage, the use of this method often presents problems. Industry, as I suggested earlier, is not accustomed to intruders, and industrial workers do not like being watched. There is therefore a danger that a-typical behaviour will be observed. It is probable, however, if the researcher becomes fully accepted in the ways which I have described, that he can make authentic observations in many situations in industry. This applies in particular, for example, to Works Committees and canteens, where visitors are often regarded as ' part of the furniture,' as it were. Recent work in the United States also suggests that the method can be used successfully on the shop floor. The latter, however, is very expensive in terms of time and personnel required, because the observer must be about for some period of time before he is accepted as ' part of the furniture,' his range of observation is necessarily restricted, and his observations must be fairly protracted

before they can be accepted as a reliable guide to typical behaviour.

The technique known as participant observation, when the researcher takes a job in a works and conceals his purposes as an investigator, has also been employed in industrial research. It can be used to make preliminary observations as a prelude to more systematic work ; to make an intensive study of the internal structure of a group ; and to check on data obtained by other methods. Personally, however, I regard it as of very dubious value for research work inside factories. Its use raises an important ethical issue. When we are undertaking collaborative research of the type which I have described, which aims at an understanding of the social system of the workplace as a whole, and the results of which it is intended not only to publish but to make available to the people in the situation, I don't think that we may also seek to ' spy ' on them by means of participant observation. In any case, its use may involve all the dangers which are likely to result if the investigator is ' found out,' and like direct observation by an ' outsider,' it is expensive in terms of time and personnel.

Experiment is another technique which has been used little, but whose desirability is beyond question, for it is only by experiment that we can give the stamp of authority to our conclusions about functional relationships in a situation. Once again, however, there are serious methodological difficulties in the way of developing more precise experimental work. In the social field there is, for example, the problem of control, and of allowing for the fact that the persons concerned will normally be aware that an experiment is taking place. Experiment in a broad sense, however, is coming to occupy an important place in current work. As the results of a piece of research are ' fed back ' to the people concerned, a process of discussion is promoted, and changes may be initiated as a result. Although, as I said earlier, it is important that the researcher should withdraw as this process develops, it may be possible for him to return after some lapse of time in order to make a systematic assessment of the influence of the changes which have been made.

Anthropology and Industrial Research

Although I have, for reasons which I stated at the outset, concentrated in this paper on the approach and methods of industrial research, many similarities between anthropology and industrial sociology will be apparent from what I have said. Most industrial sociologists will readily acknowledge their debt to anthropology but, whether the debt is honoured or not, the important feature is that similar concepts and methods have been found valuable in the most contrasted social fields—pre-literate societies and advanced industrial communities.

What are the more important similarities between the two ? We both, I think, adopt the holistic view of the social system of the unit we are studying, and recognise the interdependence of its component elements ; we are both concerned with the description and analysis of social structure, if by this we mean the persistent uniformities in social relations which are of primary significance in relation to behaviour ; we both utilise the concept of culture to embrace the uniformities of thought and behaviour which we associate with particular elements of social structure, although some anthropologists would of course give the term a broader definition ; we both speak of function when we are discussing how the parts of a social structure are related to the whole ; and we are both finding that we cannot ignore personality, even for the understanding of social structure—it is perhaps significant that Kardiner is working in the field of social anthropology at a time when the Tavistock Institute has taken up industrial research. In our methods, we find common ground in our use of direct observation and non-directive techniques, although the anthropologist has used the former more extensively than the industrial sociologist. The value of what Professor Firth has termed ' micro-sociology ' is, however, now recognised in industrial research (6), and although our increasing use of non-directive methods probably owes most to social psychology and psychiatry, the influence of the ' depth ' interviewing often undertaken by anthropologists with key informants should not be overlooked.

Since we have so much in common, the differences between us are, in the main, differences of emphasis. The industrial sociologist has been more concerned with developing techniques for entering the field and for maintaining his role once there. Although differences in conditions may largely account for this, it is surprising that the literature of anthropology appears to have so little to say about it ; I find no discussion of the problem in, for example, Professor Nadel's *Foundations of Social Anthropology*. If anthropologists develop more work in Western Society, they could draw with advantage upon the experience which the industrial sociologist has accumulated in his quest for research facilities.

The industrial sociologist has had to develop a frame of reference which enables him to take into account the interplay of formal and informal social organisation, and his work has been more ' problem-centred.' Here again his social *milieu* has been influential, but again his experience can be of value to the anthropologist, who is concerned increasingly with the impact of Western Society on the simpler peoples. Under these conditions, too, the anthropologist is likely to become the adviser of the colonial administrator, and to find that the industrial sociologist's preoccupation with ' problem-centred ' research and social change has been useful for him.

I do not think that I need say anything more about methods for collecting data, but perhaps I might be permitted to make one general observation. If the industrial sociologist has on occasion adopted a structured or over-systematic approach prematurely, the anthropologist has perhaps not always realised its importance, and has sometimes been too wont to generalise from the primary unit to the society. We are both, however, moving in the right direction, for as the industrial sociologist now recognises the importance of non-directive techniques and of direct observation as essential preliminaries to a more structured and systematic assessment, so the anthropologist is coming to see the latter as a desirable means of amplifying the significance of his observations and free interviewing. The work of Prof. Fortes on the Ashanti family (7), and of Conrad Arensberg and Lloyd Warner in modern industry (8), are excellent examples of this trend in anthropology.

In conclusion, looking at the broad picture, I think that the similarities far outweigh the differences between us, and that our differences are in any case complementary ones. Perhaps the happiest auguries for the future of both our disciplines are their common insistence on an approach to general theory through intimate, first-hand acquaintance with facts, their common emphasis on the comparative study of social processes, and their common concern for the social conditions which make for the effective development of personality.

References

(1) Chester Barnard (1949). *The Functions of the Executive*, Cambridge, Mass.

(2) T. S. Simey (1953). ' The Analysis of Social Problems.' *Sociological Review* (new series), I. 1.

(3) W. H. Scott (1952). *Industrial Leadership and Joint Consultation*, Univ. Press of Liverpool.

(4) Carroll, L. Shartle (1950). *Leadership Aspects of Administrative Behaviour*, Presidential Address, Division of Business and Industrial Psychology, American Psychological Association.

(5) Elliott Jaques (1951). *The Changing Culture of a Factory*, Tavistock Publications.

(6) Raymond Firth (1944). ' The Future of Social Anthropology,' *Man*, 8.

(7) Meyer Fortes (1949). ' Time and Social Structure ; an Ashanti Case Study,' in *Social Structure, Studies presented to A. R. Radcliffe-Brown*, Oxford.

(8) C. M. Arensberg and D. Macgregor (1942). ' Determination of Morale in an Industrial Company.' *Applied Anthropology*, I.
W. Lloyd Warner and J. O. Low (1947). *The Social System of the Modern Factory : The Strike—A Social Analysis*, Yale.

CYBERNETICS

At the Meeting of the Association in Liverpool, Section A (Mathematics and Physics), Section I (Physiology), and Section J (Psychology) devoted the morning of Tuesday, September 8, to a joint discussion of Cybernetics. Dr. E. C. Cherry, Imperial College, gave an introductory sketch of the modern interest in the subject. Dr. W. E. Hick, University of Cambridge, discussed the impact of information theory on psychology with special reference to the measurement of skill. Dr. D. M. MacKay, King's College, London, showed how the theory of autonomous artefacts, if properly disciplined, could provide a tool for the study of the mechanical basis of mind.

The three papers are printed below in the order in which they were delivered.

Organisms and Mechanisms—an Introductory Survey.

by

Dr. E. C. Cherry

In the year 1834 André Ampère wrote his *Essai sur la Philosophie des Sciences*, in which he coined the word *la cybèrnétique* to mean the 'science of government'; the word κυβερνήτης means 'steersman' (1). Government, whether it be in the sense of administration of a country or business, or the control of our own actions is analogous to the steering of a ship; it implies an element of stability, a more determinate behaviour, a canalising of activity into streams of varying straightness and narrowness, directed towards some general goal.

Such analogies as this and others between human activity and mechanical structures, have in the past formed little more than similes. Our language shows how naturally we make such comparisons. We speak of 'the man at the helm,' 'self-control,' or of a man 'running off the rails'; there are many common expressions which suggest parallels of thought in different studies such as sociology, psychology, or mechanics. But so long as comparisons remain mere metaphors they serve little more than a linguistic purpose. It was Herbert Spencer who pursued this interesting cul-de-sac to its end, by elaborate description of human organs in terms of mechanical transportation and signalling systems, factories and defence units, and who spoke of the 'dominant and subordinate centres' in both the human nervous system and in societies (2).

It is of importance in science to distinguish between a metaphor and an analogy, and further, it is essential not to read even into a true analogy the right to take over a scientific method from one field to another unless the bounds of validity are clearly expressed. Our modern interest in these cybernetic analogies—systems of government or control, whether in human affairs, the animal body or the machine—represents a crystallisation of certain limited aspects of these older similes into an exact mathematical science; the name 'Cybernetics' is again used by Wiener (3), who has been largely responsible for this modern interest. This crystallisation is by no means complete, which adds to the excitement; nevertheless, out of a great mass of mathematics and experiment, it is possible to see form and shape. The mechanist (vitalist) controveries in the days of Descartes were strictly academic; to-day the interest has spread to the market place, for not only can we discuss machines which have a certain man-like behaviour—we can make them too. The public has usually been content to leave the scientist to his mysterious pleasures in the small back room, but when it begins to scent Leviathan rising from the sea it takes notice and adopts attitudes of self-defence. That section of our Press which caters for the needs of the educated public has acted well as a

Scientific Liason Officer in reporting the results of research and in predicting the effects which discoveries may have upon the lives of its readers ; but sometimes the temptation to lapse into science fiction is too great. When the lay reader sees reports of machines which can play chess, or which can write sonnets he may feel his humanity and intelligence to be insulted. A pause to enquire how *good* a game, or a sonnet, might ease his mind, but when he reads of ' calculating machines which will replace a thousand clerks ' he feels his livelihood threatened, and could be forgiven if he started reaching for the poker.

But the revolution which modern electronic machines have brought to our living has shown up remarkably few Luddites. The development of ' cybernetic ' machines, to which man-like behaviour is sometimes attributed, is likely to have profound future effects on our bodily labour and even more upon our mental labour.

Machines which show a certain similarity to human behaviour are conveniently divided into two classes, exhibiting respectively body-like and mind-like functions. The former may be called ' Servo-mechanisms.' Simple examples are gun-laying devices, thermostatic controls and many other automatic regulators used in industrial processing plants, or again the automatic pilot which keeps an aeroplane on a prescribed course. All such mechanisms are provided with a datum of equilibrium (' goal to seek ' ; ' instructed ') [1] such as an enemy target to be tracked, a temperature, pressure, or position to be steadily maintained, or a predetermined flight-route to be followed. Servo-mechanisms are similar to other machines except that they are provided with (' sensory ') devices which detect departures from or errors in the preassigned datum (' goal ') ; such detectors pass ' information ' to control elements (' effector units ') which reset the machine on to its ' goal.' Such a cyclic flow of information is called *feedback*. The animal body abounds with similar servo-mechanisms which regulate our temperatures, our pulse rates, breathing rates, our balance and so on. The latter class of machines we call ' automatic calculating machines.' Just as all our modern mechanical gadgets, the lathe, the loom, the bicycle . . . show a steady evolution from the most primitive tools, so these high speed calculators are lineal descendants of the abacus. No fundamental, revolutionary changes in principle have occurred ; the machines have steadily increased in scale, in speed of operation and in complexity. To-day the rate of evolution is rapid, largely because of the introduction of electronic techniques. As mechanical tools, especially servo systems, have come to be regarded as extensions of the body, so calculating machines from the abacus onwards may be accepted as extensions of the brain. A modern high-speed digital computor performs calculations at lightning speed, but there is no stage in its operation which could not be performed by a human : the machine is merely faster. Again, the machine does not ' think up ' its own problems, but has been provided with a programme : a sequence of controlling coded signals (' instructions ') which determine what operations it shall carry out and in what order ; it is as inevitably tied as a slave to his master. Just so, it may be argued, we ourselves are not entirely free, isolated beings in a void, but are tied to our fellows by complex paths of communication. Can we ourselves be said to ' think up ' our own problems, unaided ?

It would be pointless here to discuss detailed comparisons between machines and the human body or brain ; the reader will certainly have seen many articles and papers, the content of which we need not duplicate. In all this work, our modern interests seem to be best served by discussion of *function*, not mechanism ; of what machines and brains appear to *do* not of what parts they are made or of how they are put together. Again, in such work one can see two particular escape hatches through which we are tempted to climb to avoid intellectual dilemma. The first is the idea that a brain is so overwhelmingly complex in its structure that we can never make a machine like it ; this is undoubtedly true, but is an unsatisfactory way of dismissing a point of principle by appealing to practice. The second is the statement that questions like : ' Can a machine think ' ? are

[1] These expressions are anthropomorphic terms, often used in machine/brain analogies.

meaningless—mere linguistic statements ; this is also true, yet again is unsatisfactory because, behind such questions we instinctively feel there is a idea of value. The dismissal of questions as ' meaningless ' can sometimes be, like Dr. Johnson's view of patriotism, ' the last refuge of scoundrels.' The question is perhaps best altered to read : can we take such concepts as thinking, learning, recognising . . . and discuss them in terms of physics and mathematics ? How much may established physical and mathematical theory contribute to problems of psychology and of physiology of the nervous system ? A great deal of mathematical analysis has been made, relating to servo-mechanisms, and a number of general concepts have emerged; at the level of behaviour, these mechanisms and the human organism may profitably be examined together in the light of such concepts and theory (3). It may also be true to say that, so far, little of practical utility has been accomplished, except the most important achievement of uniting people from different scientific fields of science by stronger bonds of understanding. In these times of increased specialisation, any valid unification of concepts can serve a most valuable purpose.

One of the functional concepts which runs like a path through various fields, to some extent linking them together, is the concept of *information* ; information flows through all communication systems, radio, electrical, human or mechanical ; it traverses the nervous system of the animal body, and it is manifest in the body social as a vital basis of economic, governmental and cultural activity.

During the past twenty-five years, a considerable body of theory has been built up around the concept of ' information ' ; this has largely been due to the work of mathematically-minded communication engineers, in an endeavour to describe what it is that their systems communicate. Recently, this theory has attained new importance by treating signals, together with the information they communicate, on a statistical basis (3), (6), (4). Once this work was done, its generality was widely recognised. Numerous scattered attempts have been made to extrapolate from the well-defined engineering field into broader aspects of human communication ; such interpretative work is fraught with pitfalls, one of the best-hid being confusion between psychological and physical notions. Since our present meeting includes both psychologists and mathematicians perhaps it will be well to indicate briefly the sources of certain misconceptions.

When we speak or write to one another, we do not transmit our thoughts—we transmit physical signals or signs : sounds or printers' ink. It is these signals which inherently bear information, or physical evidence about the originators' thoughts. We may regard this ' information ' at a number of distinct levels.

First Level of ' Information ' : Statistical Rarity of Signals

The word ' information ' can be interpreted in several ways ; but if it is to be given quantitative measure it must be defined carefully. Let us imagine some channel of communication, comprising a source (emitting signals representative of some language, code or, in certain channels, a scale of measurement) and a receiver. Then the first level at which the source may be said to transmit information forms the business of the telecommunication engineer ; he is interested not in the meaning, or in the usefulness or value inherent in the meaning of his message-signals, but only in their correct transmission. The source emits signal elements which represent letters, Morse dots and dashes, or symbols of some kind, each selected from a definite set, an ' alphabet,' which has been agreed upon by the communicating parties. Each transmitted element communicates information, since it represents one out of a possible range of alternatives afforded by the set, or alphabet. Then the ' information ' content of the message-signals may be defined as the minimum number of yes-no answers required to specify their selections from the set (roughly analogous to the game of Twenty Questions). Suppose, for example, we have a set of eight equiprobable signal-elements ; then any one of them may be specified by answering the questions : Is it in the first half : yes or no ? In the first half of that half : yes or no ? In this case three such answers

will always be sufficient, since $2^3 = 8$. Fig. 1 illustrates these eight elements

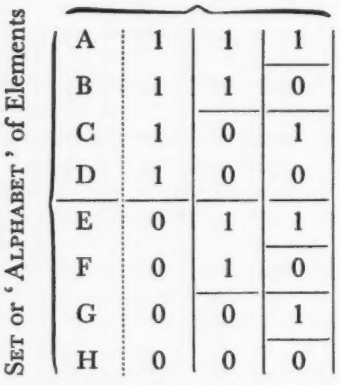

Fig. 1

Selective Information : Binary selection of Equi-Probable Message-signal Elements

(called there A, B, C . . . H) and the successive dichotomies. If we cypher the answer *yes* as 1 and *no* as 0, then each element may be cyphered by three *binary units*. In general, with N equiprobable elements the least average number of binary units is $-\log \frac{1}{N}$ per element.

However, in many sources of messages the various elements in the set employed do not have equal probabilities of occurrence (e.g. the letters in printed English). It may readily be shown that the minimum *average* number of binary yes-no answers now required, H, is given by $\text{av}(-\log p_i)$ which may be written :—

$$H = -\sum_i p_i \log p_i \text{ } b\text{inary dig}its \text{ } (bits) \text{ per element,}$$

the average, or expected, log-probability of the elements in the set. Notice that, in such cases, the average number of selections for any *one* particular element $(-\log p_i)$ may appear fractional ; and we cannot have fractions of a logical yes-no answer ! Thus we must talk only of average *rates* in bits/element from the source and not discuss the ' information in a particular element.'

Such a ' rate of information ' then refers purely to the selection of physical signal-elements out of a set or ' alphabet,' and has no concern with any linguistic or meaningful attributes they may possess ; it is convenient to employ the term ' selective-information ' for this engineering measure. But the set of signal-elements may well comprise a list of words, code-symbols, phonemes . . . anything we wish ; and the rate of selective-information is measured relative to the particular chosen set, in terms of the probabilities of these elements.

The word ' probabilities,' in this context, is to be interpreted objectively as ' relative frequencies,' estimated from past observation of the particular source. Psychologists may possibly be more interested in subjective aspects of probability theory—in terms of ' degrees of belief ' (7) —but the numerical measure of selective-information content is strictly based upon physical signal-elements given out by a source, and upon their relative frequencies, not upon how probable signals may ' appear ' to a human speaker or listener. The theory as developed so far is based on statistically *stationary* sources ; the relative frequencies concerned are assumed to be unchanging with time. Such assumptions may be wholly invalid in a discussion of many human communication problems.

Semantic or ' Meaningful Information '

The second level at which ' information ' may be considered, in human communication, arises as soon as received word-signals are assumed to be meaningful—that is, to refer to designata. The *semantic* (meaningful) information is wholly unrelated to the rate of selective-information because of the quite empirical relation between words and their designata ; in language (the word *paper* and the stuff you are holding are not causally related, but empirically : by agreement). This assumption, by a listener, that the sound he hears corresponds to certain words, and hence to designata, raises the whole fascinating psychological problem of *recognition*. Everybody speaks with their own peculiar accent ; we never hear ' perfect words,' but only samples of spoken sounds. Words themselves have the nature of Universals. The act of identifying 'words' (and designata) from a sample of spoken sound is an act of inductive inference, which proceeds from the particular to the general. The whole communication

process is one of inductive inference, a faculty so markedly possessed by the human brain and one by which we overcome uncertainties of accent and of noisy environments, and by which we by-pass handicaps of half-knowledge; the faculty of judicious guessing. We design our language to help these faculties; we conform to rules of grammar and syntax; we have conventions of speech which give clues about our accents; we stress or repeat difficult words; and it is a fact that those words that are most infrequent are longest syllabically—we say more about them—whereas the most frequently used words are short (*the, of, it, to . . .*). All such additional material, clothing the bare bones of some idea to be communicated, is called *redundancy*.

Pragmatic or 'Personal Information'

The semantic content of messages is basically abstracted from a particular recipient: he may be regarded as any member of the relevant language group. Such 'meaningfulness' of messages, as may be taken to be common to all these members, relates to the invariants of the reactions of all of them to the message stimuli. Such abstraction is of course an idealisation. But there is a further aspect of any message which is not so invariant and which affects in detail what any recipient *does* when he himself receives the message. Most messages have personal significances which vary, depending upon who receives them. For example, suppose you read in the newspaper:

Hurst Park. 2.30. Sundown. 4 lengths.

then the thoughts stimulated in you and the reactions you make, depend upon whether you have any money on this horse. Aspects of messages which concern their senders or recipients are called *pragmatic*. (8). The whole past experience of the recipient, experience of similar situations and of the particular source of messages, together with past errors or successes, are brought to bear upon his identification of message content and, in turn, influence his reactions.

The problem of recognition of a universal from a specific physical stimulus is partly a pragmatic one; different people may make different identifications of geometrical shapes, of written letters, or spoken words, depending upon different past experiences; their reactions, indicative of such identifications, will differ.

Conclusions

'Cybernetics' is the name given to a wide variety of self-regulating systems, electrical, mechanical and human, which show certain functional analogies in their behaviour. Some attributes of their behaviour show similarities, such as 'courses of action,' 'degrees of stability,' 'adaptation to environment,' and all have this in common: that data circulates in closed-path cycles carrying 'information.' This word has a variety of meanings and, when machines and living organisms are discussed in such contexts, care should be taken to distinguish at least three meanings corresponding to three aspects of communication: the signal (sign, token) selective-information content, the semantic and the pragmatic aspects.

Bibliography

(1) Ampère, André (1834). *Essai sur la Philosophie des Sciences*. Paris.

(2) Spencer, Herbert (1877). *The Principles of Sociology*, Vol. I, Part II, Chap. II (Society is an Organism) and Chap. IX (The Regulating System). Williams & Norgate, London.

(3) Wiener, N. (1948). *Cybernetics*. J. Wiley & Sons, New York.

(4) Cherry, Colin (1952). 'An History of the Theory of Information,' *Proc. Inst. Elec. Eng.*, 98, Part III, September 1951, and also *Amer. Scient.* 40, No. 4 October.

(5) Jackson, Willis (1952). (Ed.) *Proceedings of a Symposium on Applications of Communication Theory*. Butterworths Scientific Press, London.

(6) Shannon C. E. and Weaver, W. (1949). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.

(7) Good, I. J. (1952). 'Rational Decisions,' *Journ. Roy. Stat. Soc.* (Ser. B.), XIV, No. 1.

(8) Morris, Charles. "Foundations of the Theory of Signs" *Intern. Enc. of Unified Knowledge*. Univ. of Chicago Press, Illinois.

The Impact of Information Theory on Psychology

by

Dr. W. E. Hick

Introduction

Wilfred Trotter said, 'Any approach to the truth is a threat to the personality.' It is too soon to say how Psychology will ultimately deal with the bit of logical

truth contained in Information Theory. All I can do here is to mention briefly one or two things that have actually been done in the field of Experimental Psychology.

I must begin by emphasising that by 'information' I mean 'selective information': that which is measured by the negative logarithm of a probability. The theory based on this definition is often, and rightly, called Communication Theory, but that is unfortunately apt to suggest merely things like telephones and radio; properly, it is a fundamental part of the general theory of information, and hence of the theory of knowledge.

Secondly, I must leave out of consideration all applications to brain-physiology, important though they may prove to be. Psychology, in so far as it is what we call 'objective,' is 'black box technique.' By observing what goes in and what comes out, we seek to abstract laws relating them. No such observations, by themselves, can tell us about the machinery inside. Yet the divorce is not absolute; when we know, as we do, something about the internal machinery, further inferences about it can be suggested by 'black box' laws—that is, by input-output relations.

In terms of informational analysis, the 'black box,' whether living or not, plays the dual role of communication channel and code-changing transducer. In the study of human behaviour, the stimuli we apply represent messages, or parts of messages; and the responses we record are the received communications. All this, of course, is to be understood in the sense of 'as if.' Within a certain field of discourse, it is as if the human being were a channel along which information flows, and so on. These analogies are convenient, emancipating, and, within their proper limits, perfectly accurate. But are they fruitful? That is what I hope to show.

Applications in Psychology

Broadly speaking, informational analysis has been applied in three areas of experimental psychology:

(1) Hearing, language and speech.

(2) Reaction times. This includes a number of activities characterised by the making of quick choices at various points.

(3) Learning, in the general sense of modifications of knowledge or skill by experience or practice.

Language and Speech

The first of these—language and speech—is a highly specialised field, well-tilled by the philologist, the communication engineer and several other experts, as well as by the physiologist and the psychologist. I will only mention one example, in connection with the recognition of speech.

If words are spoken at random from a pre-arranged list of, say, four words, each word has a selective information content of log 4 units, or 2 'bits.' That is, there are 2 bits of uncertainty or missing information as to which word will come next at any point. If the background noise is raised until the listener can just hear practically all the words correctly in a long run, he is getting just enough auditory information to separate these four words. If, now, a much bigger selection of words is used, say 1,000, the information per word is nearly 10 bits or five times as great as before. The interesting thing is that apparently, on the average, the words now have to be repeated about five times to ensure 100 per cent. recognition, with the same background noise.

This example is elementary, but it is noteworthy for two reasons. First, if you try to avoid using information terms, the description is awkward and leaves you with a feeling of 'so what?' You would have to try a variety of lengths of list before the logarithmic relation would become apparent and even then it would be just another of the host of logarithmic curves fitted to biological data without rhyme or reason. In short, without Information Theory, who would have thought of doing the experiment and, what is more important, who would have remembered it when it was done? A theory earns its keep if it does no more than keep facts alive until they are needed.

The second point is that the listener is evidently able to remember the sounds of the five repetitions long enough to average them and so decide which word was most probably spoken. There must be a limit to that: the simple 'black box' law can only hold in a restricted domain. Therefore we cannot complain that the experiment merely proved the obvious.

Choice Reaction Time

The next type of application I want to mention is the choice reaction time. The situation is that the subject knows he will receive one out of a certain ' alphabet ' of simple signals, and he is to respond as quickly as he can by some simple prearranged movement, different for each signal. Results have been obtained in a test which employed various numbers of alternatives up to 10, and in which the response was to press the correct one of ten Morse keys on which the subject's fingers rested. This was repetition of a classical experiment done in 1885. In both cases the logarithmic function given below expresses very closely the relation between reaction time and number of alternatives, apart from a difference of scale.

The signals in this test were given in approximately random order, so the information per signal was about log n units, where n was the number of alternatives used—the size of the alphabet, so to say. I.e. log n was the prior uncertainty as to which of the n signals would occur on a given occasion.

But when $n = 1$ there is no such uncertainty ; yet it is clear that some information is conveyed even when only one signal can occur, since the subject has to wait for it. In general, there is some information about time included in the response ; it tells us something about ' when ' as well as something about ' which.' It seems, for reasons I shall mention later, that we can treat the time information as equivalent to one extra alternative, equally likely with the rest, so that the total information extracted is $\log(n + 1)$, assuming the subject makes no errors of any kind. It was found that the average reaction time was remarkably closely proportional to this function.

The next thing was to see what happened when the subject deliberately reduced his average reaction time by allowing himself to make errors. In this case, some of the input information is lost in transit, since an observer, seeing only the responses, could not be quite sure what signals were given ; or, if he saw the signals only, he could not predict the responses with certainty.

However, the amount of information that does get through can be estimated, and, in order to plot it on the same graph, it can be expressed as the logarithm of an equivalent number of equiprobable alternatives. Ten actual signals were used, but the subject, by making mistakes, acted as if on the whole he were distinguishing perfectly between some smaller number of alternatives, n_e. For example, if n_e was 4, the subject was, on the average, classifying the 10 actual signals into 4 groups of $2\frac{1}{2}$ each. There is nothing more mysterious in this than saying that the average family contains $2\frac{1}{2}$ children.

The theoretical reaction time should now be proportional to $\log(n_e + 1)$, and the curves plotted were approximately in agreement with this conclusion.

Similar results were obtained in the same way from another subject, and it was found that $\log(n_e + 1)$ fits at least as well as any other curve would. The suggestion, therefore, is that the time rate of gain of information is constant, in this situation, whether one waits to collect enough information to ensure the correct response, or whether one acts before that point. In the latter case, the deficit must be made good from some other, relatively random, source, in order to select one particular response, right or wrong.

Another variant is to give the signals unequal probabilities—i.e., to reduce the input information, while keeping the number of alternatives the same. One method is to get people to sort playing cards into heaps according to various criteria ; for example, ' pictures and plain ' would be a two-way classification giving unequal frequencies. Again, it turns out that time and information are roughly proportional.

The input information can also be reduced by introducing probability aftereffects into the signal sequence. Here too it appears that the rule holds, at least for first-order effects, where the signal probability depends only on what the preceding signal happened to be. Almost certainly, with sufficient practice, more remote correlations could be acted on in the same way, up to the capacity of immediate memory.

To return for a moment to the formula $\log(n_e + 1)$, I have had to gloss over the meaning of the ' 1.' Briefly, it has to do

with the fact that there were no relevant time errors—no premature responses or failures to respond. The discrimination between 'nothing' and 'something,' so to say, was practically perfect.

But the discrimination between the n_e mathematical fictions was also perfect, by definition; and they are defined as equally probable. It is as if the subject were able to state with certainty—in an average sense, of course—which of the $n_e + 1$ phases the environment was in. In other words, an impartial observer, having no reason to think one phase more probable than another, could receive $\log(n_e + 1)$ units of information from him, per response. That is a fact, whatever the reaction time might happen to be, and it implies that the one extra possibility—that of no signal—can be regarded as having the same probability as any particular signal. Whether it really has is neither here nor there—the subject's channel capacity is such that it *can* have.

It is not surprising that reaction time, if it is related to information at all, should be related to the whole amount transmitted. The interesting thing is that the absence of a signal seems to have the same status, perceptually, as any distinguishable class of signals. Biological tradition has never taken kindly to notions of that sort; it admits (reluctantly, I suspect) that, for instance, black is as much a sensation as white or red or blue, but on the whole it has divided itself between a Newtonian caricature of the organism as remaining at rest until it is stimulated, and the opposite extreme of a sort of magical spontaneity. Common sense, however, should remind us that a living creature is never at rest and never without stimulation; to refrain from acting requires the same sort of decision as to act.

It is interesting also to reflect that the neural process, whatever it may be in detail, is neither a straight-through conduction nor a determinate computation. There is plenty of evidence that the stimulus (the incoming data) is first recorded in its raw state, without prejudice, as it were. The time thereafter is spent, not in selecting *a* response—*that* occurs almost at once—but in waiting until its probability of correctness has grown to an acceptable level. That is to say, reaction time is mainly the time required to collect a statistically significant sample from the primary memory store—or so it seems.

Reaction times for near-threshold discriminations point the same way. The finer the discrimination, the longer does it take to ensure a given probability of correct perception. It is as if one makes a rapid stream of snap judgments which accumulate to form eventually a significant sample. The fact that usually nothing is gained by waiting longer than two or three seconds is probably due to forgetting. If we provide an artificial memory-store by simply recording a large number of actual guesses by the subject, a physical stimulus quantity far below conscious perceptibility will cause a more-than-chance proportion of correct answers. In this context, consciousness is almost synonymous with confidence. What we call a sub-liminal stimulus may be one which saturates our storage capacity, so that without artificial aids we cannot attain the degree of confidence amounting to what we call conscious perception. 'Even the most elementary perceptions,' said Sir Frederic Bartlett many years ago, 'have frequently the character of inferential constructions.' There is, indeed, no doubt that they always have.

From a practical point of view, the fact that reaction time is variable, with practice, according to the probabilities in the situation and the acceptable errors makes nonsense of the popular faith in them as tests for drivers, air pilots, etc. All such skills depend largely on circumventing reaction time by foresight—good guesswork—and by knowing what errors, and how many, can safely be tolerated. Plenty of people will produce a reaction time on test of twice the normal value, not because there is anything wrong with them, but because the situation is artificial and strange and they have misread it. With the right instruction and practice, they drop down, perhaps quite suddenly, to an average or better-than-average time.

To come back to information, the rate of transmission in the classical choice-reaction experiment is some 5–6 bits per second. This remains true for practice up to a few thousand trials; but there is some suggestion that when we get up into the

tens of thousands there is an appreciable improvement, for reasons not known. Moreover, by utilising more of the subjects' motor skill than can be deployed by merely pressing Morse keys and the like, much higher rates—20 or more bits per second—can be obtained. So we are very far from being able to state a definite channel capacity or maximum information rate for the human being.

The Problem of Subjective Probability

In speaking of probabilities I have sometimes implied objective frequencies and sometimes subjective expectancies, without clearly distinguishing between them. In measuring transmission rates we are, of course, only concerned with objective frequencies. The human being, for this purpose, is only a communication channel—and a channel has no expectancies ; it only has properties.

Nevertheless, although probabilities are inferred from relative frequencies, as they are from many other sorts of data, an observed frequency is not a probability. However, if the experimenter can infer probabilities, so can the subject. At the beginning of an experiment, only the experimenter knows the probabilities of the various stimuli—that is, the rules by which he proposes to control their frequencies ; so it would be absurd to expect a subject to act in accordance with them straightaway. If we want him to be in the state which we loosely call ' knowing the probabilities,' we practice him until he appears to have reached statistical equilibrium in his performance—an observable condition which involves no necessary assumptions about his conscious or unconscious expectancies.

That is not to say that we cannot measure other peoples' expectancies at all ; we do it every day, roughly, on a three or four-point scale, say. But as soon as we try to sharpen the estimate, we realise that we are not really measuring the other person's subjective state ; for that is unobservable in principle ; we are only measuring behaviour. We may attribute it to a degree of belief, but we must also reckon with a utility or value judgment, and it is difficult to separate them—impossible in the strictest sense.

However, we are no strangers to concepts that are not exactly definable, but are nevertheless of some use. If we are willing to accept commonsense estimates, whose only justification is that most people would be in substantial agreement about them without being able to say why, Information Theory can help to clear up, or explain away, many miscellaneous psychological observations ; most of them are unimportant, but some of them do tend to stick out like sore thumbs. Often it is not necessary to work out a logarithm ; it is enough to grasp the ideas of surprise-value, uncertainty due to the number of alternatives, and so on.

Why, for instance, does one cease to hear the ticking of a clock after a time ? Because events to which one is not attending are only accorded the primitive sort of analysis which argues that what has happened hundreds of times without fail is bound to happen the next time ; and when it does, it has no surprise-value, conveys no information ; and hence one cannot be aware of it. To become aware, we must give it surprise value by marshalling the evidence against it—that a clock is only too liable to have stopped, and so on. As we do so, the tick materialises again in consciousness.

Again, why is it helpful, and probably essential, in memorising to fit the new material into a pre-existing mental or neuro-muscular scheme ? Because the scheme identifies the pigeon-holes in your memory, and you have that much less information to memorise.

Why can we judge an interval of, say, 10 seconds to within 10 per cent. or so, *provided* we are not disturbed ? And why does time pass so slowly when we are bored or otherwise uncomfortable ? Perhaps because what we mean by the passage of time, as Dr. MacKay has remarked elsewhere, is the flux of information. If we take steps to keep it at a fairly steady rate, we can use it as a clock. If we are unhappy, we tend to imagine the coming relief—i.e., to make it seem more probable. In so far as we surrender to that illusion, we are the more surprised that the relief has not yet arrived, and we interpret the surprise as extra time.

Such examples could be multiplied indefinitely. Often the interpretations

will be neither profound nor necessarily correct. But they are worth attempting, all the same. They provide an exercise for more serious theorising, and suggestions for deeper investigations. And we ought, for very shame, to have some reasonable answers to such elementary questions, or what is the good of being a psychologist?

Conclusion

The impact of Information Theory on Psychology is twofold. On the one hand, it has been shown to be the natural descriptive system for some phenomena of which exact statistical measurements can be made; and being a rational theory, it can and should be an inspiration to further progress. On the other hand, it can be used non-mathematically as a handy and enlightening concept, sufficiently general to have unifying power, yet sufficiently simple in its lower reaches to be comprehensible to nearly everybody. A familiar analogy is the idea of electrical impedance, which is precise enough to appear in the most abstruse circuit analyses, yet is also simple enough to be invaluable to every radio mechanic, whether he can calculate it or not.

Let me end with a quotation from Prof. Max Born: 'Faith, imagination, and intuition are decisive factors in the progress of science as in any other human activity.' Information Theory has something to do with faith and intuition, and it certainly needs imagination to apply it.

On Comparing the Brain with Machines

by

Dr. D. M. MacKay

Introduction

When we speak of comparing the brain with machines we may mean one of three things, according to which of three quite different questions we have in mind.

We may be thinking of the question, how far does the brain resemble *existing mechanisms*, such as electronic computing machines? The short answer to this question is that electronic computors are not designed to resemble the brain: in fact they are explicitly designed *not* to resemble the brain in most of its functions of importance. A computor that developed aesthetic preferences and had occasional ideas of its own would have a limited field of usefulness, or at least a different one! Any resemblances there may be are for our present purpose trivial.

The second question is whether we could ever design an artificial mechanism or 'artefact' to *imitate* all human behaviour. Could an artefact ever be designed to frame novel hypotheses, or (notoriously) to write sonnets?

This question is slightly more interesting from some points of view. By imitation of course we should mean much more than the sort of imitation provided by a gramophone or even a walking, talking robot. In fact we are quite entitled to demand that the artefact should meet every functional test that we can think of which the brain, or the nervous system as a whole, can meet.

But the answer to this question also is fairly straightforward. Any test that we can specify exactly, or even statistically, in terms of the behaviour to be expected in given circumstances, can in principle be met by an artefact built only of mechanisms that are now available to us. The reason is that by a simple logical process we can turn any such precise test into a description of at least one mechanism that will meet it. It may be an inordinately bulky mechanism, but we shall be unable to distinguish its performance from that which we have laid down.

It follows that all arguments that begin: 'You'll never get a machine to do such-and-such,' are foredoomed as soon as the speaker has been induced to say precisely what behaviour he would regard as satisfactory. What is doubtful is whether we shall ever be clever enough to specify, even in principle, an exhaustive test for human-like behaviour. It is in this, rather than in the mechanical problem, that I believe there is anything of non-trivial philosophical interest (1).

The third question covered by our title is I think the one of greatest practical importance: how far is it possible to envisage an artificial mechanism that would not only imitate human behaviour, but *work internally on the same principles* as the brain? It is this possibility that I want chiefly to discuss. How do we set

about comparing the brain with machines in this sense? How far have we got—and how far can we hope to go? And what is the point of it all anyway?

Methods of Approach

The brain is unique in offering us two kinds of clues as to its function, in physical observation on the one hand and psychological study on the other. They are couched in very different languages, and our first problem is to find a common language in which to relate the two. Fortunately, as you will have gathered from the earlier papers, the language of information and control theory turns out to be just what we need, since it belongs in a sense to both fields.

So the first step in designing our theoretical model must be to sum up what we know of the way in which the brain handles information, at all levels from the nerve cell up to the complete organism. This gives less positive guidance than you might think, but sets negative limits on the kind of model we may envisage (2).

We next ask: within these limits, what mechanisms are there which could handle and respond to information in the same way? Again we can tackle this question at various levels. The exponents of what is called 'nerve-net theory' start with an idealised model of the nerve cell, and develop from it theoretical networks capable of complex functions (3). At the other extreme my own preference is for a statistical model of the whole system, with a flexible structure that we may hope to bring gradually to resemble the large-scale structure of the nervous (and humoral) system (4).

In our present state of ignorance a fair number of models might be designed to meet these conditions, although an increasing number are being ruled out. So our next step must be to study in detail how our model would work—and how it would go wrong,—and to go back to the brain to discover whether it does likewise. The discrepancies we find can then (if we are lucky) suggest the lines along which we should refine or redefine our model for the next comparison.

Let me give you an example. Nobody knows how the visual system enables us to recognise the shape of an object irrespective of its size. One hypothesis suggested a model in which the visual map in the cortex was rhythmically magnified and diminished in size about ten times per second, in step with the electrical rhythm of the same frequency which can sometimes be detected at the back of the head. There are of course anatomical and other tests of this model, and I do not think that it meets these very satisfactorily. But one way of testing it would be to ask: is there any way in which the mechanism could be tricked—and if so, can we trick the brain in the same way?

One obvious trick might be to present our model with a pattern whose size was fluctuating at the same rate as its internal magnifier. In the simplest form of model this could either prevent the pattern from being recognised, or at least give rise to perceptual anomalies. It is not difficult to try this trick on a human subject. A television tube can draw a square or triangle whose size fluctuates at the same rate as the electrical potential on the subject's scalp. But in several tests of this sort I have never found any evidence of anomalous perception (5). A null-result of this sort does not of course prove that rhythmic 'scanning' does *not* occur. It proves only that the hypothetical model of the process was wrong in at least one respect. I think there are other grounds for believing that scanning in the engineer's sense is unlikely to occur, but that is another story.

Progress and Prospects

From the example I have just given you may get the impression that our model-making is still at a very rudimentary stage. You will be right. There are still far too many possible models that cannot yet be ruled out on the evidence we have (6). Some will fall gradually by the wayside, like the digital-computor model, as other models are evolved which beg fewer questions. Choice of a model is much more a matter of intuitive judgment than of strict deduction.

Among the less explicit though none the less important restrictions on model-making is the requirement that the brain as modelled must have been capable of *growing that way*. This has led some of us to investigate the possibilities of self-organising

statistical or ' probabilistic ' models. By a statistical model we may mean (*a*) one whose elements *function* deterministically but whose detailed interconnections are assumed to *form* more or less randomly (7), or (*b*) one whose elements function indeterministically, to some controllable extent.

The model that I think promises to be most useful is statistical in both these senses (1, 4). Its basic feature is the ability to adjust the rules of its own activity according to the degree of success it attains ; but it does this, not by throwing switches, but by adjusting the relative *probabilities* of different patterns of activity. Its rules, in other words, are grown statistically as a result of its own trials and errors. The interconnections between elements are not hard and fast, but have each an adjustable probability of functioning, which will in general depend on the location and the timing of all neighbouring activity.

You might picture a typical element as something like a gun with a rather uncertain trigger. The farther the trigger is pulled, the greater the probability that the gun will go off. If now we suppose that when a gun goes off, its firing alters the tension in the trigger of another gun, without necessarily firing it, we have the basic model of a mechanism that alters the probabilities of its own activities. I wish it were possible to go into more detail. But perhaps you can see roughly how a network of such elements, if supplied automatically (as a thermostat is) with signals to indicate success or failure, could use them to alter the probabilities of sequences of actions so as to grope its way more and more quickly into a pattern of activity to ' match ' any incoming patterns that persisted in recurring. Its good guesses, so to speak, could be made to persist, and its bad ones to drop out. But because its activity would never be uniquely determined by the input, there would always be room for occasional spontaneous attempts to try something new as a ' matching-response ' to the flux of events. With a hierarchical structure these attempts could include guesses about the relative probabilities of other guesses, so that abstractions of any order could be evolved (1).

Such a model is sufficiently general to be capable of any activity we may care to specify, and it bears promising resemblances to the human nervous-and-humoral system. But if it survives the next twenty years, our only reasonable certainty is that it will have grown almost out of recognition. If it has not, it will have been of small service.

This brings us to our third question. What *do* we hope to achieve by all this ?

The Function of Theoretical Models

You will probably have gathered part of the answer already. A theoretical model of the sort we have been discussing is intended to serve as a tool of research. We can think of it as a kind of template which we construct on some hypothetical principles, and then hold up against the real thing in order that the discrepancies between the two may yield us fresh information. This in turn should enable us to modify the template in some respect, after which a fresh comparison may yield further information, and so on. The model as it were ' subtracts out ' at each stage what we think we understand, so that what we don't yet understand sticks out more clearly.

You will see at once that we shall judge a good model for this purpose not so much by the success with which it imitates or predicts, but rather by the clarity with which its failures enable us to infer what to modify next. To be sure, our aim is to approximate more and more to the real thing. But we may easily be misled into an approximation process that doesn't converge. It may even pay us to scrap one model for another which at first offers us fewer numerical predictions, if the first show signs of requiring one or more additional hypotheses for each phenomenon it encounters ! It is worth remembering, in these days when predictive ability is so often confused with understanding, that the epicyclic ' theory ' of planetary motion would have been less at a loss to account predictively for the anomalous motion of Mercury than Kepler's theory which displaced it !

Our second criterion of a good research model is that it should not only function

normally like the brain, but that it should also *go wrong* in the same kind of way. As we have seen, our model is tested most severely, and is of greatest potential value, in the study of cerebral *dis*orders rather than of normal function—difficult though it is to draw the line between the two.

It is possible that some of the mathematicians among us may tend to feel that no theory is worthy of the name until it has produced some *equations*. But I want (if I dare) to emphasise that what we want to understand in such multidimensional problems would be very little illuminated even if we could produce a gigantic equation relating all the variables that we should never measure.

Understanding, here as always, means knowing as far as possible what to expect in given circumstances, and what to infer when it doesn't happen. The difficulty is that the data, on which we want to organise our expectations by means of our theory, are mostly not measureable variables but qualitative abstractions from function. So it is only a small part of our aim to develop equations leading to numerical predictions. This satisfaction we must cheerfully leave to folk with a different type of problem.

But behind this approach to the study of the brain there lies a more general motive. It is the hope of providing a working link between the concepts of psychiatry, physiology and anatomy. Co-operation now between these fields is hampered by the sheer difficulty of imagining physiological correlates of some psychiatric terms and vice versa.

Now the language of information and control lies in a sense in between the language of psychiatry and physiology. In the information-flow diagram of a successful model we may hope to find features representing concepts from each language. Some of the data of psychopathology even now can be translated into terms of information-flow so as to suggest testable physical hypotheses.[1] I need hardly say that this is rather different from naïvely assimilating mental disorder to the ills of digital computors—a pastime which has justifiably irritated those more painfully close to the problem.

To summarise, the considerable effort going into this theoretical model-making is justified chiefly by the hope that out of it may come a way of describing the thinking process, sufficiently close to psychiatric realities to be useful in diagnosis, yet sufficiently operational and objective to allow the physiologist to make his maximum contribution to the study and treatment of mental illness. You might call it conceptual bridge-building: an activity set about with pitfalls and attractive to cranks, but withal one of the most promising ways of enlarging our understanding of what happens when we understand.

Postscript on Perspective

May I end with a word of warning. This kind of enquiry is often misconceived, and sometimes attacked, as an attempt to 'debunk Man.' People say: 'If my actions are nothing but the end-products of chains of physical causes, where do my decisions come in?' And it may of course be true that people who do wish to debunk Man imagine that a complete physical explanation of his brain would be grist to their mill. But if so I believe that they err in company with their opponents who accept the same premiss.

The villain of the piece here is usually the phrase 'nothing-but'—the hall-mark of what we may call reductionist thinking. If I say that an electric advertising sign is 'nothing-but' a certain array of lamps and wires, I may mean one of two things:

(*a*) I may mean that an electrician could make a complete catalogue of all that is there, and have nothing left over, without mentioning 'the advertisement.' This is true.

(*b*) Or I may mean that since there is nothing left over from the electrician's account, there isn't really an advertisement there at all. This is the error of reductionism. It consists in confusing *exhaustiveness* with *exclusiveness*. The electrician's account is *exhaustive* at least in the sense that a perfect replica could be constructed from it. But the electrician's account and the advertiser's account of 'all that is there' are not mutually

[1] I have in mind, for example, those hallucinations that suggest diversion rather than absence of the signals that should correct the internal matching-response.

exclusive. The advertisement is not something to be fitted into a gap in the electrician's account. It is something that we find when we start all over again to describe what is there in another complementary language.

It is not even possible to defend reductionism by the principle of Occam's Razor, for this refers to a choice between alternative descriptions in the same language-system, and not to a choice between descriptions in alternative language-systems.

I suggest then that to try to find gaps for ' my decision ' in the physical chain of events in my brain is like trying to find gaps for ' the advertisement ' in the electrical description of the sign. My decision should find no place because it belongs to a different language, defined not from the observer's but the actor's standpoint. There may well be links in the physical chain which have a certain margin of indeterminacy ; but merely on linguistic grounds it would seem absurd to seek to fit ' my decision ' into what gaps they provide. My decision is surely rather my description from my standpoint of the whole pattern of activity, determinate and indeterminate.

It is not because I believe my brain to work indeterministically that I judge myself to be responsible. On the contrary, the more physically reliable my brain is, the less excuse I have from my responsibility. There is an unpredictability that goes with my responsibility, but that is something different. It is the unpredictability to you of what I shall do if you *offer* me your prediction. As a little thought will show, you would never be able to cope with this by allowing for the effect of your prediction on me, since I should always be one jump ahead of the data on which you could base it.

To sum up, I believe most seriously that man is ' more than ' the physical organism we can describe in observer-language. But I believe that this implies, not necessarily that there must be gaps in the physical account of his activity, but that he has other *aspects* that are revealed only by using another complementary language to describe the same activity, which in its full nature transcends and combines what can be said in each.

To explore the implications of such complementarity may throw some light on the age-old paradox that though we are but dust, we are held responsible in the sight of God our Maker. But of this responsibility, whatever our attitude to it, no increase in our understanding of the brain can relieve us.

References

(1) See e.g., the Symposium on ' Mentality in Machines ' (Wisdom, Spilsbury, MacKay) : *Proc. Arist. Soc. Suppt.* (1952).

(2) See e.g., Grey-Walter, W. (1953). *The Living Brain.* Duckworth.

(3) Most of this work has appeared in *Bull. Math. Biophys.*, from 1943 to date.

(4) MacKay, D. M., in *Proc. 8th Conference on Cybernetics, 1951*, Josiah Macy, Jr. Foundation, New York.

(5) MacKay, D. M. : ' Perception of patterns modulated at the alpha-frequency,' *E.E.G. Clin. Neurophysiol. 1953*, 5, 559–62.

(6) Readers interested may consult the eight pages of references given by Stumpers, F. L., in ' A Bibliography of Information Theory,' *M.I.T. Report*, February 2, 1953.

(7) See e.g., Ashby, W. R. (1952). *Design for a Brain.* Chapman & Hall.

THE PHYSIOLOGY OF ATHLETIC TRAINING

At the Liverpool Meeting of the Association, Section I (Physiology) devoted the whole of Friday, September 4, to a symposium on training for athletics. Papers were read by speakers engaged in various sports as well as by physiologists, and stress was laid on methods of training and on the maintenance of fitness. The morning session which was concerned with the physiology of athletic training was opened by Prof. A. Hemingway, University of Leeds. Prof. A. V. Hill, C.H., O.B.E., F.R.S., Past President of the Association, was Chairman of the afternoon session at which papers were read on practical aspects of training for athletics in man and other animals.

The papers have been edited by Dr. D. H. Strangeways, The Queen's University, Belfast, and are printed below.

Physiological Factors in Athletic Performance

by

Prof. A. Hemingway

Reasons have been sought for the improvements in athletic performance, particularly in middle and long distance running, which have occurred in recent years. Many factors have operated including better selection of athletes, severer competition and improved facilities for practice but it seems possible that a fuller understanding of the physiology of muscular activity and the application of some physiological principles in systems of training have played an important part. Although only running, which is one of the most fundamental parts of athletics, will be considered here, much of what apertains to it is applicable to other sports and games.

For almost all forms of athletic performance muscular strength is required, and the conditions which lead to the development of strength and of local endurance in muscles will be dealt with in a separate contribution to this symposium. But the largest and strongest of muscles do not by themselves make a champion runner, and we know that even the most accomplished athlete can run at maximum speed for only a short distance, say, 100 to 250 yards, or at slower speeds for longer distances.

The energy for muscular contraction is supplied by chemical reactions occurring in the muscle. Primarily these reactions operate without oxygen ; they are anaerobic reactions. One of the end-steps of a complicated breakdown and rearrangement of the molecules in the muscle is the formation of lactic acid from pyruvic acid. But the amount of energy which can be obtained from these reactions is limited, and after a certain number of contractions the muscle is incapable of undertaking any more work ; it is fatigued. During and after these anaerobic contractions some lactic acid passes into the blood. The sprinter depends mainly upon these anaerobic reactions and his performance is little affected by whether he breathes or not during the period of his run, and maximum speed is perhaps mainly limited by the physical properties of his muscles. The effort of the long distance runner is terminated either by run-down of precursor material or by accumulation of lactic acid, but he ekes out his limited anaerobic resources by a continued use of anaerobic processes.

In the presence of oxygen a ' secondary ' series of reactions—aerobic reactions—takes place. The important point is that in the presence of adequate supplies of oxygen pyruvic acid is not converted to lactic acid but itself undergoes oxidative breakdown. Alternatively, lactic acid which has been formed can be converted back to pyruvic acid and employed in the cycle of oxidative reactions.

Anaerobic and aerobic reactions are not mutually exclusive, and the anaerobic reactions, limited in the amount of energy which they can supply, are only employed in circumstances when the rate of energy liberation and expenditure outstrips the rate at which the aerobic reactions can be maintained by supplies of oxygen carried to the muscles by the blood. The problem in maintaining a contest where endurance counts is how to derive the maximum proportion of the energy from aerobic rather than from anaerobic reactions.

How does training help an athlete to improve his performance? Comparisons have been made between trained and untrained subjects who undertook exhausting exercise on a moving belt (1). The results are crudely summarised in the accompanying table.

Comparisons of reactions of fit and unfit men to same rate of exhausting work.

	Fit	Unfit
Resting heart rate .	lower	higher
Return of heart rate to resting value after work . . .	faster	slower
Maximal oxygen consumption . .	higher	lower
Blood lactate during work . . .	lower	higher

The differences between the two classes of subjects are of degree rather than of kind because, if the rate of exercise is made sufficiently severe, the trained man can be brought to exhaustion within a similar period to the untrained man running at a slower rate. In these circumstances his heart rate will be as high as that of the unfit man, his blood lactate concentration may be even higher; but during the exercise period, and presumably enabling him to continue, the rate of oxygen uptake by the trained man will have been much higher. Rates of oxygen uptake of 5·3 and 5·2 l./min. respectively have been observed in two first-class athletes.

It seems unlikely that, in ordinary circumstances, the lungs and breathing, as far as they are concerned with the volume of air breathed, are involved in the limitation to severe exercise. In the experiments described the vital capacities of the trained and of the untrained were not markedly different. Nor does the amount of air passed through the lungs apparently determine limitation.

The trained athlete is apparently more efficient in using oxygen from the air passing through the lungs; probably because his breathing, for a given volume of respired air per minute, is deeper and slower than in the untrained, so that a larger proportion of the air passes into the lungs proper and is not merely passed to and fro in the larynx and trachea. And for a given rate of working the volume of air breathed per minute is reduced by training. The volume of air which can be passed through the lungs by voluntary overbreathing is much larger than is ever attained during exercise.

On teleological grounds, it might be expected that during training there would be an increase in the oxygen carrying power of the blood or of its buffering capacity against accumulating lactic acid. In fact, there are no such changes, as is shown by the experiments in 1941 of Robinson and Harmon (2), who observed nine physical education students through a course of six months' training. The resting haemoglobin and plasma protein concentrations in the blood and the changes which occurred during hard muscular activity were unaffected by training.

The maximum output of the heart is probably one of the limiting factors in exhausting exercises. During the last decade the development of measurements of cardiac output by catheterisation has given direct evidence during light exercise about the relationship between cardiac output and oxygen utilisation and has provided calibration for the indirect methods which have to be used during hard exercise.

It seems to be generally accepted that there is a roughly linear relationship between the heart output and the rate of oxygen uptake when free rhythmic muscular movement, such as running, is undertaken. But while the untrained man may not be able to increase his rate of oxygen uptake beyond 2·0 l./min. and

his heart output as far as 15 l./min., the trained athlete, as we have seen, may be able to take up more than 5 l. of oxygen per minute which would require a heart output of about 40 l.

But it would be wrong to leave the impression that athletic capability is determined solely by the potentialities for transporting oxygen from air to the muscles. The severe training methods followed by present-day long distance runners such as Zatopek, who may run an aggregate of 100 miles each week, aim at increasing the strength of both the skeletal muscles and the heart and also at improving the efficiency with which oxygen is used in the muscles. The athlete endeavours to make optimum use of the oxygen which is available by running usually at a constant pace and by employing an economical style. For instance, at a given pace there is an optimal length of stride (3). Both practical experience and laboratory experiment (4) show that preliminary exercise—' limbering-up '—improves subsequent performance and seems to produce its effects through a local increase in temperature of the working muscles. Whether the change in temperature directly affects the properties of the muscles or operates by increasing blood flow is still uncertain.

References

(1) Robinson, S., Edwards, H. T. & Dill, D. B. (1937). *Science*, **85**, 409.
(2) Robinson, S. & Harmon, P. M. (1941). *Amer. J. Physiol.* **132**, 757.
(3) Högberg, P. (1952). *Arbeitsphysiol.*, **14**, 437.
(4) Asmussen, E. & Bøje, O. (1945). *Acta Physiol. Scand.*, **10**, 1.

The Control of Breathing during Exercise

by

R. G. Bannister

The physiologist and the athlete approach the study of athletic training with different aims. The physiologist hopes that a study of the adaptation of the body to such stresses will throw valuable light on its integrative function ; the athlete hopes to discover from it the ultimate limits of effort and endurance. This paper suggests some ways in which the physiologist may be able to help in the selection of athletes and in the measurement of the limiting factors in different athletic events, especially those factors related to the control of breathing.

Not everyone is able to benefit from athletic training. Can the physiologist select those potential athletes possessing the physical and dynamic attributes needed by champions ? An early attempt to classify physique was made by Hippocrates who described two basic physiques : *habitus phthisicus* and *habitus apoplecticus*, the extreme thin man and the extreme fat man. A similar principle is used to-day, though Sheldon has added a third extreme : the muscular or mesomorphic man. It seems that athletes tend to have a physique high in both mesomorphy and ectomorphy (*habitus phthisicus*) and low in endomorphy (*habitus apoplecticus*). Somatotyping, however, has in general only confirmed the less scientific observations of coaches and trainers who select a man for a particular athletic event ' by eye.' Other physical methods have been used but these are, as yet, somewhat empirical. It has been suggested that using a formula based on height, weight and heart size it may be possible to pick out those individuals with high athletic ability, but it is unlikely that such formulae will have any practical application. It might seem hardly worth while for an athlete to prove his ability if it were possible for a physiologist to predict with accuracy the degree of his success. At rest, the athlete may show signs of increased activity of the cardio-inhibitory centre, causing a low, irregular pulse. There is one case of a world record holder who fainted during the course of a medical examination ! It seems that the athlete only comes into his own when he starts his exercise.

What are the factors which limit athletic performance and how can they be affected by training ? There is, of course, no absolute limit in theory to any physical performance, but various physiological factors cause the margin by which records are broken to diminish steadily. The nature of these factors depends on the particular athletic event. The sprinter who is running at nearly 25 m.p.h. or the javelin thrower whose arm travels at almost 60 m.p.h. before the release of the

missile, are limited by such internal factors as muscle viscosity. Such factors are innate properties of muscle which can be influenced little, if at all, by training. The sprinter does not suffer from the effects of oxygen lack until afterwards. Whether he takes a breath or not during the course of a 100 yards race is unimportant because there is insufficient time for oxygen to pass from the outside air to the muscles.

In weight lifting, on the other hand, the speed of action is at the option of the athlete. Sheer force or mass of muscle is what counts and suitable training with static exercises can develop it. The discus thrower and the shot putter require both speed and force and so the type of training they must undergo includes both static and dynamic exercises.

The greatest scope for athletic improvement probably lies in the distance events. What prevents an athlete from running at a greater speed for a longer time? If he has not taken an adequate supply of carbohydrate in advance his blood sugar concentration may begin to fall. In the 1924 Boston Marathon, for example, the winner and runner-up both showed normal blood sugar concentrations but four of the runners who collapsed afterwards showed on analysis blood sugar concentrations of less than 50 *mgm.* per cent. It is perhaps not surprising that in running races over even longer distances than the Marathon, when fatigue has set in, neuromuscular co-ordination may limit the performance. Innate co-ordination of a different type provides the limiting factor in many field events. There are some athletes who, however great their strength and spring, could never be taught pole-vaulting because they could not master the co-ordination of a series of intricate movements.

But the main factor which limits the performance of the distance runner is lack of oxygen. Since the capacity for oxygen uptake can be greatly improved by training it may be helpful to consider in more detail the way in which different factors in the oxygen transport mechanism of the body are integrated during exercise. The rate of oxygen uptake by the muscles themselves increases and is coupled with increases in the cardiac output, the speed of diffusion of oxygen across the pulmonary epithelium and the ventilation rate of the lungs. As a result of these changes the muscle fibre receives about fifty times its resting oxygen supply. Some of the factors responsible for the increase in ventilation rate may now be considered in order to illustrate methods which, though at present used to elucidate the physiological mechanisms concerned, may in the future be applied directly to training problems.

There has been much discussion of the rise in ventilation during exercise and the part played by oxygen lack and carbon dioxide excess in the body in causing it. Difficulties arise because it is not practicable to measure directly the gas tensions in the arterial blood during severe exercise and indirect methods must be used. The changes in alveolar CO_2 tension, as measured by an automatic and expiratory sample, are thought to reflect closely the changes in arterial blood tension and it has been shown that a rise in arterial CO_2 tension occurs during exercise. This has been underestimated by previous sampling methods and we have recently suggested (1) that the rise in alveolar CO_2 should be measured not from the start of exercise but from the post-exercise minimum. This is a lower level following some time after the cessation of exercise and is caused by the raised temperature and accumulation of lactate resulting from the exercise. The rise in ' effective ' CO_2 stimulus measured in this way is probably responsible for a large part of the increase in ventilation during exercise.

Even with this method of measurement of alveolar CO_2 tension, the ventilation during breathing high concentrations of CO_2 at rest is considerably below that which occurs during exercise. Some have thought that reflexes from the limbs might be this ' missing factor,' but recent experiments (2) suggest that arterial anoxaemia may be responsible. Four subjects performed severe standard exercise on a ' treadmill,' while breathing controlled mixtures of oxygen and air. In atmospheric air the subjects gave up the exercise from exhaustion after 8 minutes. When breathing 33 per cent. oxygen their performance was much improved while with 66 per cent. oxygen they appeared able

to continue running indefinitely. A fall in ventilation rate and a rise in alveolar CO_2 tension occurred when high concentrations of oxygen were breathed. This and other evidence suggest that when oxygen is added to the inspired air during exercise, the chemoreceptor drive caused by arterial anoxaemia is removed. An actual reduction of the oxygen saturation of arterial blood during exercise was considered unlikely by most physiologists until recently.

Even if there are other weak links in the body which prevent a man from running faster for a greater time, reduced oxygen saturation of the arterial blood seems to be the most important primary factor. This conclusion can be applied to training in two ways. First, the athlete may attempt to increase his oxygen uptake by training, as an alternative to enriching the inspired air with oxygen. It has been shown that the trained man is able to take up oxygen at a higher rate than the untrained man. This enables him to keep up severe exercise for a longer time before calling upon energy liberated as a result of anaerobic mechanisms, which are inefficient because they result in the liberation of lactic acid. The form of training adopted by modern distance runners imposes the intermittent stress of oxygen lack on the body, allowing time for partial recovery between each effort. Such training, instead of resulting in breakdown, causes an increase in the uptake and transport of oxygen in the body. The second way in which the athlete may apply these conclusions to his training is by increasing the efficiency of his running and hence reducing his oxygen consumption. All unnecessary muscular tension of arms, chest and head must be replaced as far as possible by controlled relaxation. Since the oxygen consumption rises considerably with a small increase in the speed of running, it is important to cover the distance at as even a pace as tactical consideration will allow.

At high altitudes the oxygen saturation in a climber's blood is reduced in exactly the same way as in violent exercise, not because the muscles are taking up too much oxygen but because the pressure of oxygen in the atmospheric air is insufficient to oxygenate the blood. The climber has resorted to breathing oxygen to conquer Everest. The apparatus used at present is too cumbersome and inefficient to give much help to a runner but it is clear that if he were to find a practicable way of breathing high concentrations of oxygen, no long distance records would be beyond his grasp. Whether such help is justifiable in what is, after all, a sport, belongs more to ethics than to physiology.

Can oxygen ever have an adverse effect on performance? In the experiments already described it was found that the inhalation of pure oxygen resulted in exhaustion in 12 to 21 minutes, whereas three of the four subjects, when breathing 66 per cent. oxygen, had not reached their breaking point when they stopped running after 23 minutes. Three out of four subjects claimed a feeling of elation and the ability to continue indefinitely when breathing 66 per cent. oxygen, while both effects were absent when pure oxygen was breathed. The reason for this adverse effect of pure oxygen is not known, although the subjective comments may point to a change in cerebral circulation. In any case, no oxygen apparatus at present in use could give a sufficiently high inspired oxygen concentration for this difficulty to arise.

In conclusion it seems that though the study of training methods is helpful both to the physiologist and the athlete, the methods themselves, being dependent on more factors than it is possible at present to analyse, are likely to remain empirical.

References

(1) Bannister, R. G., Cunningham, D. J. C. & Douglas, C. G. (1953). In preparation.
(2) Bannister, R. G. (1953). *J. Physiol.* 120, Proceedings Physiol. Society.

Circuit Training

by

G. T. Adamson

Over the past two years the Department of Physical Education in Leeds University, in co-operation with the Department of Physiology, has carried out research on physical fitness and has designed a form of fitness-training called *Circuit training*.

Fitness is very difficult to define and even more difficult to measure, but throughout the history of physical education it has been a consistently accepted

objective. The final test of fitness seems to be the ability to do the task required without undue fatigue. General fitness if it exists, has been considered in this study to be composed primarily of muscular and cardiovascular fitness, and the qualities of fitness subject to measurement and control have been muscular strength, muscular endurance, circulo-respiratory endurance and power.

Muscular strength is the capacity of an individual to exert single explosive force against a resistance, such as a dynamometer. It increases during the process of maturation, but we have found in a controlled experiment that the all-important strength/weight ratio can decrease if the fitness-training habits of the individual are not simultaneously accompanied by controlled strength-training.

Muscular endurance is local endurance based on strength and represents the individual capacity to perform localised movements at submaximal strength and high rate for a long time, that is the capacity to do relatively hard localised work without accumulating a maximum oxygen debt. The number of repetitions of the movement indicates the amount of endurance ; as, for example, in chinning a bar or sawing wood.

Circulo-muscular endurance is general endurance, depending more on cardiac condition and the efficiency of the respiratory-circulatory mechanisms than skeletal muscular strength. It represents the individual capacity to continue submaximal contractions of a number of muscle groups, with sufficient intensity to make demands on the functions of respiration and circulation. This kind of endurance enables an individual to run at relatively high speeds or work at near maximum capacity for long periods without undue exhaustion. It is likely that good ' milers ' can circulate blood two to three times faster than non-athletes. Tests are usually based on cycle ergometer pedalling, box stepping or treadmill running.

What is often referred to as ' power ' depends on skeletal muscular strength and speed of muscular contraction, and represents the individual capacity to perform sudden movements with maximum effort. The best test of the ability to develop power is the Sargent Jump, which fairly accurately measures the maximum vertical height through which an individual can project his centre of gravity by jumping off both feet.

A comparison between champion athletes and the average individual in the performance of tests designed to estimate these four qualities of physical fitness is shown in the table below.

The overload principle appears to supply the answer to the problem of control of the above qualities. Overload for strength and power, either by imposition of progressively greater loads or higher work rate, produces increase in muscular strength by hypertrophy of all the individual fibres. As a result of this increase in strength the fewer motor units required for a given load may be alternated for a longer time, thus increasing muscular endurance. Specific overload for muscular endurance, for example progressive practice of ' sit-ups,' is effective mainly through the improved blood supply to the

TABLE I

TYPE OF FITNESS	MUSCULAR STRENGTH	MUSCULAR ENDURANCE		CIRCULO-RESPIRATORY ENDURANCE	MUSCULAR POWER
Test	*Strength/ weight ratio.*	*' Chins '*	*' Dips '*	*5 min. step test*	*Vertical jump in inches*
Champion :					
Gymnasts . . .	8·6	11·3	17·6	—	23·2
Athletes . .	7·8	13·2	19·3	108·6	23·6
Swimmers . . .	6·5	12·5	11·0	122·9	24·3
Average individuals .	5·3	4·3	6·2	79·8	18·7

muscle. Overload of large muscle activities such as exercises involving severe leg work, in addition to increasing the strength and muscular endurance of those muscles concerned, induces hypertrophy and increased capillarisation of cardiac and peripheral muscle, thereby increasing circulo-respiratory endurance.

Circuit training based on the overload principle is designed to develop the four aforementioned qualities. The well-known and easily performed exercises provide strong developmental work for arms, legs, trunk and also general stamina training. They are arranged in the form of a circuit round the gymnasium so that quite a large group of performers can be accommodated at one time. The activities are so arranged that the performer can progress round the circuit without undue local fatigue. They are such as allow of a fairly accurate assessment of the amount of work done. Each individual's maximum performance at each activity is ascertained by a preliminary test and his training rate is fixed at a certain proportion of this maximum : one half or one third, according to individual condition. The performer laps the circuit, keeping strictly to his prescribed rate. He works for half an hour, and the eventual objective is to lap the circuit three times in the half hour. Periodically, the individual's maximum performances are re-measured and his training rate altered accordingly.

The following table shows the percentage increase over the initial value in the various tests.

TABLE II

INCREASES OF MEANS

(As per cent. of initial values)

MUSCULAR STRENGTH	(L R) Grips	8·1
	Push and Pull	4·6
	Back	9·3
MUSCULAR ENDURANCE	'Chins'	44·1
	'Dips'	76·4
	'Shins'	77·9
CIRCULO-RESPIRATORY ENDURANCE. .	Harvard Step Test	6·9
POWER . . .	Vertical Jump	12·3

This training, on what might be called sub-maximal overload, has proved popular with students and has produced considerable increases in fitness levels.

MODERN APPROACH TO DISTANCE RUNNING

by

G. H. G. Dyson

THE training aims of the distance runner from the physiological point of view are three-fold. First, he must diminish his oxygen requirements for a given exercise by running with an economical style and at as even a pace as possible ; secondly, he must increase his oxygen intake as a result of improving both volume and rate of the heart beat and by ensuring (mainly through lack of tension) an adequate return of blood to the heart ; and thirdly, he must adapt his body to higher concentrations of lactic acid.

In the world of track and field athletics we differentiate between running 'technique' and 'style.' The technique of running is in conformity with certain mechanical principles and it concerns essential movement as opposed to the physical peculiarities and mannerisms of a runner's style. Thus half a dozen runners may each have excellent technique and yet so stamp their movements with the marks of individuality that an uninitiated onlooker might think they were running in six different ways. Zatopek's running in the 1948 Olympic Games is a case in point ; a majority of the spectators and press reporters were seeing the great Czech athlete for the first time and were so concerned with the agonised expressions on his face and the way he rolled his head from side to side that they assumed that his running action was a poor one. Actually Zatopek's running technique is ruthlessly efficient ; it stands up well to the critical analysis of the slow motion camera and, indeed, if it were not so he could not run as he does.

Two distinct methods are used by modern distance runners to increase their oxygen intake and to adapt themselves to greater concentrations of lactic acid : one the *Fartlek* (a Swedish word for 'speed-play') and used by Gundar

Haegg of Sweden, and the other *Interval Running*, used by Emil Zatopek of Czechoslovakia.

Haegg who holds the world record for the mile, is a product of the Swedish countryside and carried out most of his training in the woods, by the lakes and up and down the hills which surrounded his home. He never trained on a track because he felt that it was a monotonous form of training likely to lead to staleness. He thought, also, that continuous practice on the cinders developed a hard type of muscle unsuited to distance running. Haegg maintained that by going to a track only to race he was more inspired by the occasion. He disliked formality in training and set himself no pre-arranged running exercises or timed distances. He relied entirely on how he felt from day to day. He was naturally supple and believed that earlier work on the farm had given him a good physical background requiring no gymnastic exercises.

This great Swedish athlete trained in all weathers and frequently 'punished' himself, but although he was often tired after an outing he knew that all was well if the next morning he was eager to run again. In the winter, when the snow lay thick upon the ground, he would train five or six times a week along ski trails. Starting with walks and slow runs he covered never less than three miles a day, building up over the weeks to run through deep snow which often severely taxed him. Later, when the snow had disappeared, he began the speeding-up period, running over the soft pine needles which cover the floors of the Swedish forests. At this stage of training he would begin by running six miles easily and then, after a week or two, would introduce fast stretches of 200 to 800 yards, gradually lengthening the spurts and shortening the easy running periods as he felt he was getting fitter. When the athletic season began he raced only when he really felt ready and at first against easy opposition and over short (1,500 metre) distances. From here on he trained lightly, relying on frequent competitions to keep him in good trim. In 1942 he raced thirty-four times in fourteen weeks, breaking ten world records in that time.

Emil Zatopek is the holder of man world records and is the only man in history to win the 5,000 metre, 10,000 metre and Marathon events (each in record time) in one Olympic Games. He, like Haegg, was born in the country and spent his childhood and much of his youth on a farm. However, for most of his time as an athlete he has been a town dweller. Running as well as ever, he is now a physical training officer in the Czech army, living in a Prague flat. Like the Swedish runner, he trains every day and in all weathers and is in fact never out of training. He bases his preparation on a mixture of fast and slow running all the year round. In the winter either in the Sokol riding school in Prague or along the roads, wearing a track suit and heavy army boots. But the bulk of his training each year takes place on the track and consists of slow and fast running. He gradually increases his daily schedule to a mixture of as much as six miles of slow running and twelve miles of fast. Before one important competition two seasons ago he was known to run sixty 400 metre fast laps (with 200 metre bursts at the beginning and end of the workout) every afternoon for the ten days immediately before the race. As he cheerfully keeps up this sort of thing all the year round monotony seems to hold no terrors for him. He does not compete as often as Haegg, but keeps on with his training right up to the day of the competition, and continuing with it the day after.

I have spoken of two different approaches to training for distance running but you will notice they have much in common. There is a theme which runs through the preparation of both Haegg and Zatopek and it is one which is found in the training programme of any first-rate distance runner. There are in fact basic principles of training and they may be summarised as follows :

(1) *Function determines structure* and a tremendous amount of running is necessary for the gradual building up of the runner.

(2) *Fast and slow work must be mixed* in order to improve the ability to work under maximum concentration of lactic acid and with high oxygen debt.

(3) *The distance runner must be strong:* his whole body must be in good condition.

(4) *There must be ' overloading ' in training* as strength and endurance only improve when he trains with greater intensity and for longer duration.

(5) *A certain callousness towards fatigue must be developed.* The great distance runner can run himself out, if need be, to a far greater degree than the average athlete. These men learn that to feel tired is not to *be* tired. They can drive themselves beyond the psychological limit, whereas the novice slows down or stops.

(6) *A runner must cultivate a knowledge of pace and tactical sense.* These are interdependent and without a knowledge of pace (best learnt in training) and a tactical sense (which can only be acquired in competition) a distance runner will fail to run with an even distribution of effort. It is worth noting that neither Haegg nor Zatopek had any special training of pace and judgment.

7. *There must be proper balance between training and competition.* A runner cannot train a lot and race a lot.

8. *A sound training and racing programme develops self-confidence.* It makes the athlete aware of his real potentialities and gives him a familiarity with and a healthy contempt of the distance to be run.

9. *Nutrition and rest are important* although athletes have excelled in these events on a wide variety of diets.

10. *The distance runner must love to run* and running must be an important part of his life. It is by no means unusual for these athletes to put in as much as a hundred miles of training each week for months on end, and to fit this into their normal family, social and professional lives. Indeed, Pindar's words in the 11th Olympian Ode are as true of the distance runners of to-day as they were of the Greek athletes he had in mind : ' Without toil there have triumphed a very few.'

The Attainment and Maintenance of Fitness in the Racing Greyhound

by

J. K. Bateman

(*Read by Prof. E. C. Amoroso*)

The attainment of fitness in the greyhound really starts before birth when the health and living conditions of the dam must be carefully controlled. Exercise and an ample balanced diet are essential. Whelping as a rule is easy and the litters average about five or six, each puppy weighing about 1 pound at birth. The kennel must be kept free from draughts and at a temperature of about 65° F. The puppies require no special care during this period, except sometimes protection from their dams, and they grow at a rate of about 2 ounces a day. At the end of three and a half weeks, almost as regularly as clockwork, they make for the door of the whelping bay. Progress is then rapid and they should be allowed a run of about 20 feet. Weaning comes at about four weeks when they are fed on a mixed diet plus calcium lactate and cod liver oil. At five to six weeks they are treated for round worms and vaccinated against leptospiral jaundice. At ten weeks they are removed to the rearing area, that is, to country cottage, farm or large penned-in field and here they remain for the next year merely growing, feeding and exercising. Anyone who wants to rear a greyhound puppy well must believe in freedom, exercise and ample food as the basis of his work. As in all animals it should be borne in mind that the spring or late winter puppy does best as it meets the rougher conditions of the country while the weather is warming up and is nine to twelve months old before the winter.

At about twelve to fifteen months the puppy, now called a *sapling*, is brought into a kennel. He dislikes the confined conditions and the restriction of a lead and collar but he will quickly settle down and his training can begin. The training consists of gallops of increasing length in company with older and more experienced animals of both sexes. The progress of regular work is continued on a progressive scale until he is taken to a track. In the early stages he tends to gallop awkwardly on the bends and it is not unusual for him to injure himself because of this awkwardness. If *track leg* develops it is prudent to arrest his training on the track until he is made so fit by galloping on a straight course that he will be able to take bends in a collected fashion. From now on, if he is a genuine dog (and there are sham greyhounds in the sense that they will either not chase at all, cease to chase owing to

lack of interest or display an innate tendency to fight) he will rapidly improve both in pace and track craft and will gradually learn to leave the starting box at speed and develop a sense of judgment and determination.

When training is completed a fit dog is generally raced three times in two weeks over a distance of 525 yards, followed in the third week by a race of 725 yards. Most racing dogs run on the flat but there are some which have a marked ability for hurdling. These tend to be rather coarser framed but there are noticeable exceptions. Accidents may occur in both flat racing and hurdling dogs and it is a fact that the dog which tries hardest will meet the most serious accidents. He suffers little frustration and may break a leg when he makes for an opening.

Greyhounds, like other athletes, go stale if over raced and have to be carefully watched. Some dogs will run until they are seven years old, getting only a month or six weeks rest in the year, but they are at their fastest between the second and third year. No dog conserves his energy during a race and stop watch readings show that a really fast dog will complete 525 yards at an average speed of 37 miles per hour, with a speed of over 40 miles per hour for the first part of the course. Comparison of the speed of the greyhound with man, horse and even the speedway rider prove that over a short distance the greyhound moves faster than any.

The routine of kennel life is well-ordered and consists of gentle exercise and meals at regular hours. Throughout its life the greyhound must be fed on a good mixed diet which in the racing period should contain a good proportion of protein in the form of meat or coarse fish. The food is fed in the sloppy state and at no time should the bowel content become hard as sometimes happens with ordinary dogs. The greyhound's fitness and the type of food which he consumes ensure that his abdomen will always be nicely tucked up when he is ready to race. Dogs which race regularly twice a week require no galloping other than the races but those that are not called upon for programmes will be galloped twice or three times a week over a distance of up to 300 yards. It should be stressed that dogs needed for track racing are never sent on long distance walks on roads as are coursing dogs whose training is especially directed towards staying power.

No paper would be complete without some reference to the habits and fallibilities of the bitch. The greyhound bitch comes in season at any time after about thirteen months. Some may be earlier and others again have been known not to come in season until two years old. One noteworthy case was the bitch 'Greta Ranee,' which was whelped in May 1933 and won the Greyhound Derby in late June 1935, before coming into season. Because of her seasonal fallibilities a bitch is often put into training earlier than her litter brothers. She matures more quickly than the dogs and because of her lighter weight she gets into her stride quickly when on the track. Tenacity is also characteristic of the greyhound bitch. It is generally considered that the bitch at the point of coming into season is at the peak of her form and will run at her fastest at about this time. Experiments which have been tried in the early weeks of season have shown that all form seems to have been lost; there is no alternative to rest and paddock exercise until the minimum of eight weeks has passed.

Practical Aspects of Training Thoroughbred Horses for Flat Racing

by

J. L. Jarvis

(*Read by Wm. C. Miller*)

The training of thoroughbred horses for racing has altered little over the last half-century: proof of this is that the old families of trainers who carry on the methods of their forbears are still the leading trainers. The horses come into the trainer's hands as yearlings, at about eighteen months of age. Many are the property of, and raced by, their breeders; others are purchased at public auctions and it is thus that a trainer can lay the foundation of a successful stable. If buying for an owner who wishes to race on the best lines, that is to say, who wishes to run his horses in the classic and big races without any thought of betting and with a view

to their stud value after their racing career is over, a knowledge of the pedigree and conformation of the young stock is essential.

In the pedigree the sire should have proved himself able to get winners, or, if newly at stud, should have been a good racehorse and the owner himself of a classic pedigree. The dam need not necessarily have been a great racemare herself but should have shown she was capable of winning races and have already produced something which could race. The most important point is that she should come from a family descended from a classic winner. The bottom line (the female line) of the pedigree is the important one as, almost without exception, the winners of the classic races trace back on the bottom line of their pedigree to some great racemare.

Training of the yearling begins in about September. Breaking in takes about a fortnight and by the winter he should be able to canter about half a mile. During the winter he is kept to steady cantering and trotting exercises and is fed on as much hay as he can eat but on a reduced corn ration.

Flat racing takes place from the middle of March to the middle of November. Early in February steady cantering exercise over about five furlongs should begin and after about a fortnight this should be increased according to the distance each animal is likely to run. Care should be taken never to run a horse at top speed until he is ready for it. The main objective of training is to build up the muscles of propulsion so that at the time the horse enters a race these muscles are at the peak of their efficiency. If the training has been properly carried out the power of the heart and blood vessels will have been so increased that the circulation of the blood is at its best and the action of the lungs so improved that the blood can be supplied with its full oxygen requirement. The whole process depends on regular and balanced exercise so that improvement in tone of the whole body is progressive. A severe gallop before a horse is ready for it can do irreparable harm and may—especially in young horses—cause 'athlete's heart' (that is, a dilated condition of the heart).

A horse spends the greater part of his time in his stable and it is here that much is achieved which is of importance to his well-being. His box should be kept clean and well ventilated and he must be well groomed after exercise and again in the evening, before feeding him and shutting him up for the night. The feeding of a horse is most important when in full training and the more he eats the better. The hay and corn must be carefully selected and feeds should be given three times a day; morning, mid-day and the principal meal in the evening.

The selection of and entering for the races which a horse will run devolves on the trainer. A horse is entered for most of the important races from two to three years before they take place. It follows that in making entries for races which are of varying distances one must have a knowledge of the pedigrees which are most likely to produce the animal able to win the particular race for which he is entered. Certain families and sires produce a majority of stayers; others sprinters; and much money can be wasted by entering a foal or yearling for, say, the Derby if it has a sprinting pedigree. To win the Derby is the ambition of most owners, and the mating of most of the mares is directed therefore to producing a foal which will stay one-and-a-half miles and at the same time have a certain amount of speed. There are also owners, principally those who go in for betting, who like the early maturing sprinting type, which can be raced earlier. It follows, therefore, that many foals are bred from sprinting and middle-distance families. A lot has been written in the press in the last few years about the French breeding better stayers than we do. The reason is not hard to find: in France their principal race, the Grand Prix de Paris, is just short of two miles and they have hardly any races of less than one mile; they concentrate, therefore, on breeding stayers only, whereas we go in for breeding animals for all distances.

Trainers vary in their methods of preparing a horse on the day of the race. Many give them a short 'pipe-opener' in the early morning but, except in the case of a gross feeder, I seldom do. The horse is walked in the morning for about an hour, then groomed and his shoes

changed for aluminium ones which weigh only a few ounces : an extra ounce on the feet is equal to several pounds on the back. He is given a light feed and left quiet until about two hours before the race. He is then groomed and unless he is highly strung and excitable, is led about for about an hour before the race. Finally he is inspected by the trainer to see if he is properly saddled and bridled.

When it comes to matters of health most trainers are capable of dealing with minor troubles but the veterinary surgeon should be called in when in doubt. Trainers are becoming worried by modern methods of farming, for kiln drying of oats, spraying of the fields and the baling of hay on the field can all give rise to digestive and other troubles which demand the vetinary surgeon's help.

Training is an art, and will remain an art, not subject to precise definition or hard facts and formulae. It means knowing your horse, treating him like a human being and having common sense. Constant attention to detail, recognising differences between individual animals and allowing for, or correcting, their peculiarities, an infinite amount of patience and a gradual building up of experience are all necessary for success. While it is desirable to take all advantage of any knowledge of health and disease which science can provide, it must be emphasised that it will never be possible to train horses satisfactorily by rule of thumb methods. Thoroughbreds are 'individuals' with great differences of temperament, and methods of training must allow for this variability.

Addendum

Mr. MILLER *said he would like to add some comments to Mr. Jarvis's paper.*

He drew attention to certain important differences between human and equine athletics. In man, the athlete knew why he was performing and would always do his psychological and physiological best to win, or to equal or break a record. The noise and excitement of the crowds would affect the individual but little, and in any case would be understood. The human performer was stripped to a minimum.

The racehorse, on the other hand, did what was asked of it, but did not necessarily always perform at its maximum. The object was competitive—to beat the others—but not to break a time record. The horse had to carry up to about 10 per cent. of its body weight as jockey, saddle, bridle, etc., and had to have a tight girth around the chest and a bit in the mouth, both of which might to some extent impede freedom of movement and impair respiration, especially in a long race. For comparison, one could expect a considerable lowering in performance if a human mile runner had to carry a 12 or 14 lb. weight on his back and a strap round his chest. The neuro-muscular effort necessary for a racehorse to win a $2\frac{1}{2}$-mile race was consequently relatively greater in the horse than in man, and the test more severe. The psychological and physiological influences were likely to be more disturbing in the horse : cheering of crowds might act as a stimulus to greater effort or as an alarming experience which might make a young or nervous animal frightened, erratic in racing and less fast than otherwise. Sexual disturbances in females (*oestrus*) and less so in colts, often upset the form and led to disappointing running. The animal's neuro-muscular system was temporarily at the mercy of its emotions, uncontrolled and without a sufficient degree of self-discipline to overcome them. Finally, the racehorse had to obey its jockey, and these individuals varied greatly. In spite of all these points, the majority of racehorses definitely appear to enjoy racing and galloping.

From a more fundamental viewpoint, it should also be borne in mind that the modern racehorse had been bred to race. For a very large number of generations, thoroughbreds had been selected through the ruthless sieve of *performance*. The useless or inferior animals were not used for further breeding, and among the Classic winners the influence of ancestral selection could be noted by a study of their pedigree and performances. This had not yet happened in the human field of athletic endeavour.

Mr. Miller said in conclusion that the claim could quite legitimately be made that the modern racehorse represented the absolute peak of the art and craft of animal production and the acme of the

art of the animal breeder, by whatever standards these might be measured.

Training Professional Footballers

by

J. Lynas

I'm afraid that after the weird and wonderful things you have been hearing about this week this paper will seem rather commonplace. However, to us in the football game, football is just as wonderful and very often just as weird. This talk is unusual for it is a subject that is talked about very little, and what is probably more unusual, is rarely written about. Any trainer's methods are the direct result of years of experience and we all have our own pet theories about what is and what isn't the right thing to do with players to get them fit, and to keep them fit. When trainers get together methods of training are the last thing that are discussed. The Football Association, through Mr. Winterbottom, tried hard to organise discussions on methods in the annual courses but they bore little fruit. They can best be summed up in the words of a friend of mine who said that he came along to keep his ears open and his mouth shut. Unfortunately for him we were all there with the self-same idea. I am not referring to the courses organised by the Football Association for the treatment of injury ; these are excellent and, I am certain, are doing a vast amount of good for the players and the game in general. In the medical profession when anything new is discovered it is immediately published in the medical journals; not so in the football world. Leagues and cups have to be won, promotion gained and relegation avoided, so that if a club can turn its team out even just that little bit fitter than its opponents, then of course to advertise its methods would be throwing away what is perhaps its only advantage.

There has been little change in the methods adopted in this country since before the war, except perhaps for more ball practice. Personally I am all for this change provided that ball practice does not take the place of hard training ; and make no mistake, to get really fit to play football professionally in the top class entails a lot of hard, even monotonous work. I can remember when it was quite common for players to train for a week and not have sight of a ball from one match to another; the theory advanced for this was that they would become ' hungry ' for the ball and would chase it on the Saturday until they dropped for the kick of it.

Most clubs insist on a full month's training before the season starts. The first week is generally given over to steady lapping and half-speed running of the length of the pitch until the trainer is satisfied that the stamina of the men is fairly good. Every session is finished with various exercises either on the field or in the gymnasium. During the second week road work is introduced and is usually welcomed by the players as a break from the monotony of lapping. There is a gradual build-up of speed until, after eight or nine days, our favourite game of ' Tippy-tappy ' is introduced. This consists of an abbreviated game of seven or eight a side which gives a lot of hard work and is a valuable means of teaching young players positional play. Hereabouts, medicine ball is worth while : particularly for those players whose waistline is more prominent than it was at the end of last season. By the end of the second week we usually have our first private practice match, and to my mind matches are by far the most important factor in the pre-season training.

By the third week we begin to use spiked shoes in order to get that tone in the posterior hamstring muscles so essential to any athlete to whom speed is important. There is, I know, the risk of pulled and strained muscles but I believe the risk is worth while, for a certain amount of stretch in the hamstrings and rectus femoris muscles is essential for speed. If you picture the number of people you know who are fast on the track or if you look closely at the characteristic walk of players like Stan Matthews, Stan Mortensen, Jackie Milburn, Tom Finney and a host of others I could mention, they all have at least one thing in common, that slightly flexed knee which almost gives the impression of slouching when they are walking, but which you will probably agree is the ideal position for a quick

getaway. Pulled muscles are the bug-bear of this type of athlete but they can be prevented by constant stretching or by doing particular exercises.

Perhaps one of the greatest problems confronting the trainer of a football team is keeping it fit for nine months of the year. The racehorse trainer usually has a particular date in view, so he can regulate his training in order to get one peak performance out of his charge. We have to try to keep players at the peak for nine months of the year and, what is more, to act in all kinds of conditions of the field. Another problem for the trainer is staleness. This usually develops in the New Year when players have had a surfeit of football. It is a real problem and I am convinced that when a player has lost his zest for the game, for surely that is staleness, the wisest thing to do is to let him have a complete change of surroundings and a total rest from football. Before a cup competition I am in favour of a few days change of air and surroundings but not in the week of the special match. Our experience is that in their anxiety to build the players up for a tremendous effort, the hotel people usually overfeed them with the result that instead of the team being on their toes they give a sluggish performance.

People often ask me do our players smoke and do I consider it does them any harm? While I do not think that smoking in moderation will do players any great harm, and by moderation I mean five or six cigarettes a day, I do not think it does them any good. In my own playing days I experimented with smoking and I found that even in moderation it affected me for the first ten minutes or so of the game until I got my second wind. As a matter of interest, eight of the Blackpool team that won the cup last year are non-smokers.

To my mind the psychological factor plays an important part in the winning of matches. One occasionally reads in the sporting press that such and such a team lasted the game better than their opponents for the simple reason that they won the game in the second half, and inferring that one team was fitter than the other. I do not think this is always right. There is always a turning point in an evenly contested game, and that point is usually a goal or a missed goal, and I do not think it has anything to do with training at all, it is just the psychological factor of getting a goal at the right time.

In conclusion I would like to say what I think is the finest feeling in the world. To walk along the street as though you were walking on air; to look at a bus or tramcar dashing past and to know that if you really wanted you could run after it and catch it; to look at the garden gate and feel that you could just as easily jump over it as to open it and walk in; to go home and eat a good meal without asking or worrying what it is going to be, knowing that with your appetite you are bound to enjoy it and to go to bed and sleep soundly and dreamlessly, as only a really fit person can: that, I believe, is something the average man has never known. But it is, I think, the finest feeling in the world.

Addendum

The remaining invited contribution to the symposium was given by Mr. J. Egan the text of whose paper on 'The general fitness of Rugby League players' was not, however, available at the time of going to press.

SOCIETY AND THE CALCULATING MACHINE

Sub-Section A* (Mathematics), at the Liverpool Meeting, devoted a session on the morning of Monday, September 7, to ways in which the community benefits from mathematical techniques. Prof. L. Rosenhead, F.R.S., Department of Applied Mathematics, University of Liverpool, discussed the needs satisfied by modern calculating machines. Two other members of the Department also delivered papers. Dr. A. Fletcher considered the need for mathematical tables, and their future in the light of automatic computers. Mr. A. Young reviewed the use of punched cards in science and administration.

The papers appear below in the order in which they were given.

SOCIETY AND THE CALCULATING MACHINE

by

PROF. L. ROSENHEAD, F.R.S.

I. INTRODUCTION

OUR understanding of the nature of matter has deepened rapidly within the last sixty years, and our insight in this sphere of knowledge has been verified in spectacular manner by the production of new terrifying weapons of war. The phenomenon of nuclear fission casts its shadow over the world, and at the same time offers tantalising prospects of a much desired increase in industrial power. Within a short time the consequences of a few laboratory experiments have created profound changes in thinking, in the spheres of politics, warfare, and certain aspects of industry.

But another revolution, less spectacular in its manifestations, has also taken place ; it is due to the invention of modern calculating machines and their introduction into science and administration. The splitting of the atom may have introduced new points of view into certain specialised aspects of our thought and industry, but the calculating machine, if properly used, will breathe new life into many more branches of science and administration. This revolution is already upon us, and its effects upon society are quietly beginning to appear. But the significance of what is happening should not be overlooked. We are perhaps at the threshold of a new era of science in connection with which the invention of the modern calculating machine may be as important to the world as was that of the Hindu-Arabic numerals to the Middle Ages.

In recent years newspapers have contained references to artefacts referred to by such unusual names as ' mechanical brains,' ' electronic brains,' ' fully-automatic electronic digital computing machines,' ' punched-card systems,' and the like. We have been told that these machines ' think,' ' calculate,' ' use judgment,' ' play games,' etc. The general reaction has been one of surprise and incredulity, and deep hidden irrational fears have stirred uneasily. To most people these devices seem to have appeared out of the blue, but in fact much time has elapsed since the machines were first thought of ; what is happening is that we are now starting to see the results of a great deal of careful thought and investigation, and it is the object of these notes to describe some facets of the ideas and the events which have preceded these newspaper announcements.

The engineering aspects of the machines, as well as indications of their known powers, have been described fully in the scientific and engineering press ; the object of the present discussion is to supplement these accounts by comments of a more general nature. From the outset it must be emphasised that these computers are the product of the joint skills of the

mathematician, the engineer and the inventor ; secondly, the machines contain no principles previously unknown ; they do, however, embody the elaboration and the refinement of known techniques. It may also be mentioned that there are, in Great Britain at the present time, only about twenty electronic calculating machines. It is understood that about ten of these are in working order and that on some of them a great deal of valuable work is being done : the remaining ten are in various stages of development. In America, however, about fifteen are in almost constant use, and about *one hundred and fifty* are under development. This may give a measure of the relative intensity of effort in this field in the two countries.

It is also worthy of note that the value of numerical methods in the development of science has been fully appreciated by UNESCO, and that an international centre for spreading this appreciation is to be set up in Rome for that very purpose. In other European countries projects for developing and applying electric and electronic calculating machines are well under way. In Germany two machines are working and four more are under development. In Australia, Canada, France, Holland, Italy, Norway, South Africa, Sweden and Switzerland, people are turning towards, and are working on, those new developments.

II. Social Needs

Many people have asked ' What are these machines ? ', ' Why were they ever invented ? ', ' Who wanted them ? ', but no fully satisfactory answer seems to have been given—perhaps because the answer is not simple. Undoubtedly some commercial interests have exercised great pressure in the direction of increasing the speed with which computation can be carried out, because far more arithmetic is done every day for the purpose of business and commerce than is done in all the scientific and mathematical laboratories of the wold, but indications can also be brought forward to show that speed in computation is a necessity not only in commerce but also in the interests of scientific development, national needs and national preparedness ; it has become a real need—or rather, once it has been shown that great speed in computation is possible, the need for it has crystallised rapidly.

There is a stage in the development of every society when the need to be able to compute with great speed becomes important in large-scale commerce and in planning. People in Great Britain would not be able to plan on a national scale, with any semblance of precision, for national health, national insurance, building, defence, etc., if they were unable to assemble their records in convenient form, and analyse them with accuracy and speed. Speed is essential, for otherwise the administrative machine quickly becomes clogged. This is particularly true in times of war. But, speaking generally, the need for speed in computation is a social matter and depends upon the scientific atmosphere of the times. To meet that need two types of people are required. There must be the creators, the men of brilliant individualistic ideas, and there must also be the men who appreciate the ideas and apply them. There is evidence to show that brilliant ideas are not the prerogative of any one nation or group of nations ; the history of science is full of examples in which the same idea seems to germinate almost simultaneously in the minds of scientists in different parts of the world. But there is this difference—in some countries the ideas appear at a time when there are no people in positions of responsibility who are prepared for them, so that the ideas wither. In others they fall into the minds of individuals who are ready for them, and these are the people who are responsible for the developments which later become evident. The existence of such individuals in any society, especially those people in the second category, is an index of the mental health, and of the social needs, of that society.

III. Historical

Articles on computing machines usually contain many technical terms, but in the present one the writer has attempted to introduce as few as possible. The unavoidable ones are :—

(i) *An electronic machine :* until recently it would have been correct to describe such a machine as one in which electronic

valves are used. In the light of modern developments, however, it is more accurate to describe it as one in which electricity is conducted through either an evacuated space or a gas or a semi-conductor.

(ii) *A computer :* usage is confused in connection with this word. It should mean ' a person who computes,' but it is frequently used to mean ' a machine on which computations are made.' The correct word to denote a computing machine, ' computor,' is also sometimes used !

(iii) *An analogue machine :* one in which the numbers are represented by physical quantities, for example—electric currents, of which the numbers themselves are the measures. Operations are carried out on the physical quantities in such a way as to reproduce the desired numerical computations.

(iv) *A digital machine :* one in which the numbers are stored in the machine and are represented by discrete objects, such as the teeth of a gear wheel.

(v) *A programme :* a set of instructions formulated in a way appropriate to the design of the machine ; holes punched in tape is one possible form in which the instructions may be prepared.

(vi) *An automatic machine* is one which, once the initial instructions have been given in suitable form, carries out several steps of the computation without human intervention, even perhaps giving the impression that it is exercising a form of judgment. Such machines are sometimes called ' programme-controlled ' or ' sequence-controlled.' A ' fully-automatic ' machine is one which carries out all the steps of the computation in the manner indicated above.

The idea of *automatic* computation by machinery seems to have occurred first to Charles Babbage (1792–1871) in 1812, when he was only twenty years of age. Babbage made a small automatic machine but when it came to making one on a large scale he sought and received the support of the Royal Society. This Society was instrumental in obtaining for him a grant of money from the Treasury to enable him to develop his ideas ; however, although he made considerable progress, the prospects of a continuing expenditure of money did not appeal to the Treasury, with the result that after a time both the financial support and the work were discontinued. But enough had already been discovered to show that, in principle, Babbage's scheme would have worked ; had he continued, there is no doubt that some form of machine would have been built in England though the speed would have been slow by modern standards. Unfortunately for the prestige of British engineering and science it was left to Scheutz, a progressive energetic master-printer of Sweden, to make the first machine based on the ideas of Babbage.

Babbage was certainly the first to formulate the scientific and engineering problems in this field of activity and he proceeded a considerable way towards their solution. A hundred years or so had to elapse, however, before his ideas came to maturity through the application of electric and electronic devices by engineers and scientists.

Babbage himself reported that his interest in computation was due to his own need to make navigational, astronomical and mathematical tables. It struck him that the routine processes of his work were capable of being carried out by machines, and he even looked ahead to the prospect of including a printing unit in his system. Babbage had two machines in mind—a Difference Engine and an Analytical Engine. The former was intended to be a device for sub-tabulation and nothing more, whereas the latter was to be a general-purpose programme-controlled computer with all the facilities we find in such machines to-day.

In 1822 he wrote to Sir Humphry Davy as follows : ' The intolerable labour and fatiguing monotony of similar arithmetic calculations first excited the desire, and afterwards suggested the idea, of a machine, which, by the aid of gravity or any other moving power, should become a substitute of one of the lowest operations of human intellect.' Later he extended his ideas and explored the possibility of converting into number all the formulae of mathematical analysis. Although his machines were never completed the work which he did had a stimulating effect on several aspects of English engineering by

drawing the attention of many people to the kind of work which could be done. The driving force in Babbage's approach to machinery for computation was his interest in astronomy and mathematical analysis, but his success was due to the fact that he happened to possess a gifted sense of mechanics and was thus able in his own person to co-ordinate two different specialisms.

It is worthy of note that, in addition to the reasons given by Babbage for his interest in computation, there is the fact that his father was a banker, and that from his youth Charles appreciated the importance of computations and the analysis of records.

The next really important step in the development of computing machinery as envisaged by Babbage was taken by Prof. Howard Aiken—now Director of the Computation Laboratory of Harvard University—an electrical engineer. When he was asked what made him think of developing machinery for computing he replied that the preparation of his thesis for the degree of Doctor of Philosophy of Harvard University necessitated the numerical solution of a large number of ordinary differential equations. The experience convinced him of the real need for carrying out such operations by automatic means, and this turned his attention towards the development of machinery for computation. Here again there is an example of the effect of the cross-fertilisation of two different specialisms in one person. The first date in his notebooks on which reference was made to automatic computing machines was April 12, 1937, about 125 years after the idea first occurred to Babbage.

It is worthy of note, however, that in 1936 there appeared in the *Proceedings of the London Mathematical Society* a remarkable fundamental mathematical paper by Dr. A. M. Turing, now of the University of Manchester. In this paper can be found the basis of many of to-day's ideas on fully-automatic computing machinery.

Aiken's development was made without any knowledge of Babbage's work; he said that it was a shock to him when, after having proceeded with his work for some years, he came across a reference to Babbage's papers, and there, in the writings of over a hundred years ago, he saw clearly described all the principles which he himself had deduced.

From the beginning both Babbage and Aiken had recognised how valuable it would be to produce a machine which could be used for many different types of computation. They were not concerned with the development of special machines for particular purposes, but rather with multi-purpose computing devices. Here is an indication of the needs from which sprang a recognition of the value of this type of machine.

There have been special computing machines as far back as 1642. A model was made by Pascal and it worked; but it was a toy, and the general outlook of the times was such that it was not needed in science or commerce. The art of the modern computing machine is far removed from that of Pascal's machine by, among other things, its greatly increased capacity for rapid computation, and in 1884 a young American machinist, Dorr E. Felt, completed his invention of a hand-operated, key-driven computing machine. He later became the manufacturer of the well-known commercial 'Comptometer.' Felt was in charge of a wood-planing machine and he conceived his basic idea from watching its ratchet-feed motion. He wrote: 'Watching the planer-feed set me to scheming on ideas for a machine to simplify the hard grind of the book-keeper in his day's calculations of accounts. I realised that for a machine to hold any value to an accountant, it must have greater capacity than the average expert accountant. Now, I knew that many accountants could mentally add four columns of figures at a time, so I decided that I must beat that in designing my machine. Therefore, I worked on the principle of duplicate denominational orders that could be stretched to any capacity within reason. The plan I finally settled on is displayed in what is generally known as the "Macaroni Box Model."'

The following additional points are worthy of note; they give an indication of the reasons which prompted people to interest themselves in these devices—people now well-known internationally for their contributions to the art of cal-

culating by machinery. W. S. Burroughs, whose name is associated with an internationally-known accounting machine, was a bank clerk ; Hermann Hollerith, whose name is commemorated in the well-known punched-card system, was an officer in the United States Bureau of the Census. He realised in 1886 that long before the census returns of 1880 had been analysed it would be time to have a new census in 1890. This turned his attention to machines which would speed up calculation and analysis.

The first electronic machine was designed in 1942 at the Moore School of Electrical Engineering of the University of Pennsylvania. It was called the Electronic Numerical Integrator and Calculator, or more briefly ENIAC. The desire to create it arose from the pressing need of the Ordnance Department of the United States to provide ballistic trajectories of shell and bombs at such a rate that the available computing strength of the whole of the U.S.A. was unable to cope with it. But in fact the real impetus towards the creation of this machine came in 1941 from a physicist, Dr. John W. Mauchly. His major interests were in the analysis of the considerable volume of physical observations made for the Department of Terrestrial Magnetism in the Carnegie Institution in Washington. The records were concerned with electricity in the atmosphere, magnetism in the earth, the weather, etc. He was convinced that the most efficient way of carrying out the analysis was by means of some type of electronic machine and he joined the Moore School of Electrical Engineering in the autumn of 1941, in the hope of learning something about how to use electronic valves to devise machinery for computing. It was at about this time that the Ordnance Department in Washington became alive to the need to be able quickly to produce such ballistic trajectories as might be needed. From this there resulted the development which led to the creation of the ENIAC through the collaboration of Mauchly the physicist and Eckert the electrical engineer.

The ENIAC is a digital machine ; desk calculators are similar examples ; punched-card machines provide another example in the same category. It is of interest to note that quite a number of the digital machines which in their final form are general-purpose devices actually started with a special-purpose objective ; in each case the designers found, independently, that it was as easy, and much more satisfactory, to produce a general-purpose machine which would include the special-purpose among its functions. The other major class of computing machines is that of the ' analogue ' machine ; a slide-rule is a very simple form of analogue machine. There is one important member of this type which must receive special mention—the differential analyser. This type of machine was invented by Dr. Vannevar Bush of America. By 1930 Dr. Bush and his group had finished the first differential analyser. It was entirely mechanical and had no electrical parts except the motors. A more ambitious differential analyser was started by him in the Massachusetts Institute of Technology in 1935, and was completed in 1942. This was a valuable machine, but, by and large, it is being superseded by the newer automatic electronic machines. The same problems can be solved more accurately on the electronic instruments, perhaps even more economically.

It is interesting to note in passing that when the work was almost completed, Bush found, to his great astonishment, that the principles of his machine had been laid down quite clearly by Lord Kelvin in 1876 in a relatively brief paper. This is another example of the same ideas having been generated quite independently in different parts of the world, but in England the practical need was not yet apparent. Kelvin's ideas fell on barren soil. But in 1925 Vannevar Bush, at the Massachusetts Institute of Technology, was sufficiently alive to the need to proceed as fast as his ingenuity and skill would permit him.

IV. The Growth of Interest in Numerical Methods

Interest in machinery for computing developed in Great Britain in the following way. Babbage and Kelvin were, of course, the important pioneers in this field. Before Babbage, however, there had of course been a reasonably continuous interest in mathematical tables, and many

individual mathematicians had devised ingenious methods of computing tables of logarithms, sines, etc., but their interests in numerical methods were perhaps more those of the pure than of the applied mathematician.

After Babbage, the British Association Mathematical Tables Committee, which existed from 1871 to 1948, did more than any other group in the world to stimulate and keep alive interest in the making of mathematical tables. The names of many great mathematicians are associated with this Committee : Cayley, Stokes, Thomson, Glaisher, Rayleigh, Greenhill, Forsyth, Sylvester, Karl Pearson, Airey, Doodson, Comrie, etc. Speaking generally, however, most of these people were more concerned with making tables than with Numerical Analysis. This statement was certainly not true of Pearson, Doodson and Comrie. In particular, Pearson's method of analysing observations statistically, and his expositions of his own work, gave very considerable impetus to Numerical Analysis. In 1948 the Royal Society took over the interests and the responsibilities of the Mathematical Tables Committee of the British Association.

But the people really responsible for the present appreciation of Numerical Analysis in Great Britain are Sir Edmund Whittaker, Dr. L. J. Comrie, Sir David Brunt, and Prof. D. R. Hartree. When Prof. Whittaker was a young man at Dunsink (1906–12) in Ireland, he learned of the many numerical methods used by astronomers for their own calculations and, in Edinburgh, from 1912 onwards, he learned what actuaries are doing, principally through his contacts with the late G. J. Lidstone. He found that astronomers and actuaries were, within their own special domains, using methods involving numerical analysis which were known to only very few mathematicians, and he took steps to make this information known in a wider field. Prof. Whittaker himself was not interested in machines, but only in the methods employed for solving special problems ; the well-known book, *Calculus of Observations*, by Whittaker and Robinson bears excellent testimony to the range of his interests. In his opinion the best training for undergraduates was to use relatively primitive aids to calculation. That may have been true up to some twenty years ago, but the tempo of scientific discovery has increased considerably and it is now desirable for students to learn some of the techniques of numerical analysis and statistics, using desk calculating machines, if they are to obtain experience, while in the Universities, of some of the types of problem likely to confront them later. Whittaker was a pioneer in this field, and through his students, schools of numerical analysis, ' computation ' it was then called, were established in Imperial College by Prof. Levy, and in the University of Leeds by Mr. G. Smeal. In 1917, Dr. Brunt, now Sir David Brunt, interested principally in dynamical meteorology, found it necessary to stress the importance of numerical work, and he published a very useful book entitled *Combination of Observations.* At the time when it was first published this book was the only one which gave an account of the theory of least squares without tying it up with some specialised technology ; previously the book which most people used had been written for people reducing surveys or for astronomers.

But perhaps the greatest populariser of numerical methods that this country has had was the late Dr. Leslie John Comrie, F.R.S. Comrie's earlier interests were in astronomy and in the numerical methods required in this field. Prof. Karl Pearson at University College, London, introduced him to calculating machines and gave Comrie an opening into what was to be his life's work. When, in 1926, Comrie was appointed Deputy Superintendent of the Nautical Almanac Office, he was quite convinced of the inefficiency of the then prevailing method of calculation by the use of logarithms, and he applied himself to the task of introducing mechanical methods into the routine procedure of the Nautical Almanac Office. These new methods involved the utilisation of commercial machines such as the National, and the Hollerith punched-card equipment. But he devised methods of using these commercial machines far beyond the anticipations of their original designers. It is possibly true that the capacities of these machines for numerical work have still not been fully explored.

In fact, Comrie's greatest contribution to the general advance of interest in numerical methods is that he showed what could be done with available, relatively inexpensive, hand-operated or electrical, machinery. This, by the way, was well before the time of electronic computing machinery.

A contribution of considerable importance was also made by Prof. Hartree, one-time Professor of Theoretical Physics in the University of Manchester. He was concerned with problems of theoretical physics, and realised the value of Dr. Vannevar Bush's differential analyser as soon as he heard of it. He went to America, studied the machine, came back to England and, with the assistance of an industrial benefactor and the co-operation of the University of Manchester, built a similar machine in that University. Hartree did much to stimulate interest in Great Britain in the idea of calculation by machinery.

Before this, in about 1920, the late Sir Arthur Eddington, keenly interested in astronomical problems, gave a course in the University of Cambridge on ' Combination of Observations ' ; it was on the lines of Brunt's book of the same title. Harrison of Clare College gave a course at about the same time in which ' Harmonic analysis, computation, nomograms, etc.' were mentioned in the syllabus. Levy's course in London was, in principle, in advance of the Edinburgh course in that it dealt more thoroughly with the question of the integration of differential equations and was perhaps rather more modern in its general attitude. A course in numerical analysis, and a Mathematical Laboratory, established in the University of Liverpool in 1933, were inspired by the experience of the writer when he was a student under Smeal in the University of Leeds. Later, in 1946, an undergraduate course in Numerical Analysis was also established in the University of Cambridge. The establishment of this course owes a great deal to the earlier influence of Sir John Lennard-Jones. As Professor of Theoretical Chemistry it was his need for mechanised arithmetic that lead to the construction of the second differential analyser in England, and to the foundation of the Cambridge University Mathematical Laboratory, which was for a time under his control. Bringing the account up to date, mention must be made of the post-graduate course in Numerical Analysis which has just been established by the University of Cambridge.

The general effect of this slow development was that during the years since 1913 there have been injected into the scientific stream of this country a few investigators who were aware of some of the things which can be done by the processes of numerical analysis, and these people have helped to influence the opinions of those scientists with whom they have come into contact.

But it was perhaps the two great wars of 1914 and 1939 that stimulated the armed forces of this country into a realisation of how much they depended upon numerical methods of one kind or another. The armed services exerted great pressure on their supply departments—in the first world war on the Ministry of Munitions, and in the second on the Ministry of Supply —to provide them with the answers to their problems and with new instruments of war. In the 1914–18 war a great deal of numerical work, both theory and application, was done in the field of ballistics. The work was carried out in the Anti-Aircraft Experimental Section of the Munitions Inventions Department of the Ministry of Munitions. This group operated first under the leadership of Prof. A. V. Hill, and then under the late Sir Ralph H. Fowler ; Prof. Hartree was a member of the group. There was a trajectory and computing section under the late Prof. Karl Pearson, the statistician, and Dr. A. T. Doodson, now Director of the Liverpool Observatory and Tidal Institute. In fact, the basic methods used for trajectory calculation to the present day are associated with the name of Doodson.

Before the advent of the requirements of anti-aircraft gunnery the ballisticians were required to predict only the point of fall, and much ingenuity had been spent on getting this point without calculating intermediate points on the trajectories. In the anti-aircraft requirement each point on a trajectory is equally important and so emphasis was placed on the correct calculation of the trajectory as a whole and on the development of step-by-step

methods which could be carried out in a routine manner for complete sets of trajectories, and also on interpolating points between calculated trajectories.

In the 1939 war the needs of the armed forces, in terms of numerical methods and analysis, grew to surprising proportions. In this connection mention must be made of the establishment of the Admiralty Computing Service and of the excellent work it did under J. Todd and D. H. Sadler. The work of this service did much to spread a realistic appreciation of the value of numerical methods. Each new type of projectile or bomb required a new set of trajectories. New engineering procedures necessitated calculations which had to be carried out rapidly. The rapid development of new types of weapons made it necessary to be able to make quick estimates of their possible consequences. In many cases a particular tactical problem could be solved in many ways, and it became necessary to evaluate a family of solutions and from it choose an optimum. In choosing the optimum, consideration often had to be given to questions of supply, available man-power, weight of ammunition, availability of steel, load-bearing capacity of bridges, etc. All these considerations had to be based on some form of estimate which, however speculative might be the underlying assumptions, had to be correct mathematically so as to show the logical consequences of the original assumptions. And speed was of the essence of the situation. It is interesting to note, however, that the first of the electronic machines of the modern kind to be made in England was that of Dr. M. V. Wilkes and his colleagues in the University of Cambridge. In this instance the needs of pure science constituted the driving force.

Since those days the Ministry of Supply and the Department of Scientific and Industrial Research have been the main sponsors of the introduction into England of machines for computation. Perhaps this has been so because they were aware of the great advances in this direction being made in America. But in America the impetus now comes not from Government Departments but from private commercial enterprise. In England special praise must be accorded to the Cambridge University Mathematical Laboratory under Dr. Wilkes; Dr. Turing and Mr. Womersley, both formerly of the National Physical Laboratory; those sections of the National Physical Laboratory which are led by Dr. Goodwin and Mr. Colebrook, and the Manchester University team of mathematicians and electronic engineers which is led by Prof. Williams, for spreading a knowledge of the potentialities and powers of modern electronic automatic computing machines. In this connection special mention must be made of Sir Ben Lockspeiser who, as Secretary of the D.S.I.R., has done and is doing a great deal to stimulate in this country enthusiasm for modern electronic machines for computation.

V. A Review of Existing Aids to Computation

The businessman, the administrator, and the scientist of to-day have many aids to computation at their disposal—instruments, machines, mathematical tables. In the first instance there are the simple mathematical instruments such as slide rules, planimeters, etc., which are used so frequently that they have come to be looked upon as the basic tools in the armoury of the engineer. Then there is another important tool, the well-known tables of simple mathematical functions, such as, for example, logarithms, rates of interest, products, etc. In addition there are the tables required in simple statistical calculations. These are accepted as part of the natural order of things in commerce and administration.

Next in order of complexity are tables of the more complicated mathematical functions, of especial value to scientists and design engineers. The increasing demands made on these individuals by society lend emphasis to a point of some importance. It has been suggested that the newer types of electronic machine will make unnecessary much of the present compilation of mathematical tables, as the machines can calculate whatever functions are required as and when they are needed. Although electronic computers can do this there is no basis for such a point of view. We know enough of the history of science to be able to say with confidence that the invention of any new

aid to calculation does not displace the earlier ones ; what it really does is to open up new fields of scientific and commercial activity. The abacus is still used ; slide rules are still used ; so are ready-reckoners and books of logarithms. Volumes of tables of mathematical functions are in constant demand and continue to be needed by the majority of scientists and engineers as they map out their theories and their calculations. In fact, with the growth of science and its application, the demand for mathematical tables will increase. There will also be a growing demand for electronic and electrical machines, but it is not unreasonable to anticipate that for years to come the number of installations of digital and analogue machines will be relatively few, if only on account of their cost. In addition, they are somewhat expensive to run and need specialist mechanics, engineers and mathematicians. Perhaps the situation will alter when such people are available in sufficient number and when electronic machines are cheaper than at present, and simpler to maintain.

In this connection reference may perhaps be made to two critical points. They are truisms which, surprisingly, need continued emphasis and reiteration. Firstly : machines are useless if there are no men to run them. Secondly : men, scientists, engineers and mechanics will not, in a free society, devote themselves to these newer devices unless their interest is aroused. At the present time interest in these machines is growing. Industry and science are starting to realise their potential value. And some men are already aware that these machines are of permanent value—not just a passing whim.

When considering machines it is well to keep in mind that there is a significant difference between those which carry out the operations of arithmetic, in which increasing mathematical accuracy can be achieved by reiteration and successive approximation, and those in which the accuracy of the final result depends on the details of their mechanical or electrical construction. In the former there is no limit to the mathematical accuracy which is theoretically achievable ; in the latter the limits of accuracy are a function of the tolerances of manufacture.

But returning to our catalogue of aids to mathematical calculation, note should be taken of the considerable importance of the relatively simple desk calculating machine, both the hand-operated and the electrically-operated types. It is not unfair to say that these small simple machines have proved themselves to be among the most valuable of the aids available to commerce, science and engineering. They have proved their worth for doing those preliminary and detailed calculations which present themselves from time to time in the normal run of work, and they have also proved themselves to be the best instruments for training university undergraduates and research workers to appreciate the value of numerical methods.

Then there are the well-established accounting machines. These are usually designed to meet specific requirements—single-purpose units of great value in banks, supply organisations, and the like. Especially important in the field of accounting is the technique of using punched cards. These punched - card machines have their greatest value where simple mathematical operations have to be carried out on a considerable volume of numerical information, and where the results of one part of the calculation do not immediately have to be used as input for further steps. Very often the same information has to be used simultaneously in different sections of some large firm or organisation. In such cases copies of essential information are required. But normal manual transcriptions often introduce errors, frequently difficult to trace. Babbage had the idea that if the essential information could be recorded as holes punched in special cards, and if the cards could be sorted and analysed quickly according to the information required, human errors would be eliminated and transcription would be unnecessary. Babbage suggested that the sorting could be done mechanically. Nowadays it is usually done electrically and at high speed, but it is interesting to note that the Powers-Samas machines do sort mechanically at the same speed as the Hollerith do electrically. But one essential feature of this type of machine is that it can carry out only a few simple operations while the cards are passing through it. The

larger the number of required operations the greater the number of times the pack of cards has to be passed through the machine. Further, instructions are normally given by electrical contacts in a plug-board, and as the plugging of the boards often takes a great deal of time, these machines are most useful when dealing with large quantities of numerical information, the contact board thus remaining unaltered for considerable periods of time.

The potentialities of punched-card equipment for purely scientific numerical work do not seem to have been fully explored, or, if they have been explored, have not been made known sufficiently widely. There are many problems which lend themselves to the special qualities of these machines, such as a wide range of statistical calculations, the making of mathematical tables, the solution of simultaneous linear algebraical equations and linear differential equations. It is true that most, if not all, of the work at present done by punched-card methods can be done by the newer automatic digital computers. In general, however, the two machines are suited to different kinds of problems. Roughly speaking, punched-card machines are best for problems involving a few simple operations on a large quantity of numerical information, and the high-speed computers are better for those problems in which complex mathematical operations have to be carried out on a not excessive amount of information. In problems where the feeding in of information is a major part of the work, and if this information is fed in relatively slowly, as at present, there is little point in doing the calculations at great speed. Another point to be noted is that, at present, punched-card machines have a great advantage over other types in that they are readily obtainable ; further, they need little or no modification to adapt them for the solution of any suitable mathematical problem.

The most important type of analogue computer is the differential analyser. This machine was originally designed to integrate ordinary differential equations. It is of value in those cases where information is required to show the trend of solutions with varying boundary conditions, as for example when one has to calculate the effect on a complete system, of varying initial design parameters. In such cases the limited accuracy of the differential analyser is not a disadvantage since, very often, only approximate solutions are needed. A considerable volume of calculation was carried out on these machines during the last war, such as, for example, the solution of families of equations concerned with the internal and external ballistics of guns, shells, rockets, trajectories of V1 and V2 type of projectiles, etc., and the solution of the non-linear equations of the theory of servo-mechanisms.

The differential analyser is basically a multi-purpose analogue machine with variable internal connections. If some of the internal connections are fixed, we get a type of analogue machine which can be used for the solution of variants of some one specific problem. Such kinds of machines have proved to be extremely valuable, as, for example, in simulating aircraft control systems for training pilots, etc.

But when one speaks of modern types of calculating machine, one usually has in mind those which are electronic, fully automatic, digital and general purpose. It must, however, be borne in mind that, basically, these computers can perform only the same operations as a human being. These machines should not be regarded as the forerunners of new types of creation with superhuman minds, but rather as the most stupid kind of human operator—so stupid, in fact, that they cannot make even a trivial decision of their own ; so stupid that every little step in the process of calculation has to be mapped out and the appropriate instructions formulated. Even where the machines appear to take some decision, the criteria for judgment must be laid down and embodied in the instructions.

At this stage, it would perhaps be appropriate to refer to a by-product of the invention of these types of machine. They have stimulated many people to speculate on the method by which the human brain works and some far-reaching, unsubstantiated claims have been made on the basis of apparent analogies. The mind appears to make decisions, so do these machines—and hence, it is said by some,

the mind works like these artefacts. But insufficient attention has been paid to the critical point that machines may carry out what they are instructed to do, but not a single one is able to use judgment, make guesses, intelligent or otherwise, determine all its own instructions or perceive and interpret even simple situations outside itself. Less far-reaching claims would have been more realistic and valuable. Our understanding of the physiology of the body has come about largely through the application of the techniques of physics and chemistry to a study of the living organism and by the use of artefacts which have actions analogous to, though not necessarily identical with, those of the organs of animals. In much the same way it may well be that our understanding of some aspects of the activity of the human brain will be advanced by our growing knowledge of electronic calculating machines.

But reverting to the main topic, here is a brief indication of some of the things which have been done with the aid of these machines. Important contributions have been made to the theory of numbers; functions in pure mathematics have been tabulated in cases where tabulation by human assistants would not have been economic; as a result mathematicians and scientists have been enabled to appreciate the general behaviour of complicated functions in which they were interested. Problems have been solved in atomic physics, astrophysics, the motion of compressible and incompressible fluids, solar radiation, wave guides, the ionosphere, family budgets, chess, diffraction phenomena in microscopes, surveying, weather forecasting, meteorology, census analysis, electronic valves, structures, turbine rotors, optical systems, plate fractionating towers, etc. Statistical analysis, problems of aircraft flutter, metallurgy, transfer of heat, etc., have all provided problems for these machines.

The three most recent applications which have been made public are particularly instructive. The first came from the oil industry; considerable quantities of oil (the quantity is estimated at millions of barrels) are lost annually as gas, but it now seems that if certain detailed calculations can be carried out rapidly on the site, it should be possible to control the conditions of flow to such an extent that the vaporised gas will be converted into fluid and so be saved. Electronic high speed computers offer the only way of carrying out the calculations.

The second example refers to the international laboratory which is being established near Geneva by the European Council for Nuclear Research. It is proposed to build there a very expensive accelerating device, but the practical soundness of the design has been questioned. Theoretically, an instrument constructed to precise mathematical specifications, should be an extremely valuable scientific instrument. But in practice there will be slight disturbances due to small misalignments in the fields; the effects of these may eventually build up so that an appreciable number, or most, of the accelerated particles hit the walls before they complete a sufficient number of circuits of the instrument. To test this matter it is necessary to work out a large number of critical proton-orbits. The amount of labour required to compute these paths is prodigious, but now, by the aid of the Automatic Computing Engine at the National Physical Laboratory, the computations are to be carried out in reasonable time, and so an electronic computer will provide relevant information before an important policy decision, involving a considerable expenditure of money, is taken.

In the sphere of administration, one very large private organisation in this country has already installed an electronic computer and by its aid carries out some of its routine administrative computations. This firm has shown, by direct comparison, that the machine does not make the apparently accidental errors made by its costing clerks, and also that the work can be carried out much more economically and rapidly than in the past. It has been estimated that where one of the modern-type machines can be used it can, in equal time, do the work of about one hundred clerks. So great is the importance attached to economy and the elimination of error in the computations of large organisations that the Department of Scientific and Industrial Research has started to investigate this problem in a

comprehensive manner. In particular, the working of the Ministry of National Insurance has been singled out for detailed study from this point of view. The way in which this came about is as follows. At the time when the Manchester machine was just about ready to start work, a special committee was set up at the instigation of Sir David Brunt to consider the development of computing machines, to maintain liaison between different workers producing new machines, and eventually to recommend which machines should be manufactured on a large scale. This committee, of which Sir David has been Chairman since its inception, has continued to meet regularly and has unquestionably been extremely valuable as a means of disseminating information. Some time ago the Committee became convinced that it was necessary to make a really close investigation of the possible application of these machines in big departments such as the Ministry of National Insurance, and a sub-committee was set up to consider what should be done. This sub-committee has just reported and certain suggestions have been forwarded to the Department of Scientific and Industrial Research as to the next stage in the solution of this difficult problem.

VI. Future Developments

The immediate future needs in this field of interest can be formulated quite simply. An appreciable increase is needed in the number of mathematicians and engineers capable of using and discovering the potentialities of existing automatic electronic and electric computing machines.

Next, simplified versions of existing machines must be devised, with the following characteristics: they must be much cheaper, maintenance costs must be smaller and the techniques of giving instructions must be less complicated. It will probably be difficult to satisfy this group of requirements, but only by doing so will it be possible to induce an increasing number of administrators and scientists to buy and use such machines.

If one accepts the present high speed of computation without modification, consideration must be given to methods of increasing the speed of input of information and output of results. Alternatively, if speed of input and output are accepted without change, it should be possible to build much cheaper computing machines whose speed of computation is much reduced. Basically a balance must be achieved between speed of input, computation and output, but the balance will depend on the problem considered. It is obviously uneconomic to have a three-branched system with one branch adjusted to work more rapidly than the other two.

In addition, hybrid machines will probably be developed in which will be mated some of the qualities of electric and electronic calculating machines, punched-card systems, and differential analysers, depending on the nature of the problems to be solved.

But even if these requirements will not be met within the next ten to fifteen years, the demands upon existing and projected installations will continue to increase, especially in those spheres of engineering and science in which the relevant scientific laws are well understood but in which their application to interesting cases is rendered difficult or impossible by the complexity of the mathematical analysis or by the cost of numerical analysis in which human operators and the older types of aids to computation are used. In this way, known problems which in the past have been over-simplified or put aside, will again be considered—and solutions of some kind will be obtained. These answers will suggest new problems and new speculations, and it is thus not unreasonable to anticipate a greater vitality in the whole complicated field of applied mathematics, science and engineering.

Further, the existing theoretical approach in mathematical physics, mathematical engineering, theoretical chemistry, biology, etc., will probably be altered. At present, on account of the large number of variables which enter into the real problems which occur in nature, and the impossibility of attacking by conventional mathematical methods any rigorous formulation of the detailed problems, the practice has grown up of idealising any complicated problem and devising a simplified model which contains only one,

two, three or four of the full range of variables. When these idealised problems are solved one is often in doubt as to whether the mechanical solution of the simplified problem bears any significant relation to the exact solution of the real problem, for errors may have been made in the process of idealisation. In future, the process of simplifying the problems of nature may not need to be so rigorous, for numerical analysis and the use of electronic computers may provide an approach more general than that at present available through mathematical analysis.

In the field of administration, the picture is not so clear. A great deal will depend on the attitude of private enterprise, the willingness of Government departments and large corporations to experiment with new techniques, and the experience likely to be gained during the next ten years. Perhaps the vital lead will come from America.

In the fields of psychology and medicine the position is even more obscure, but there is no doubt that there will be much discussion, and that the experimental approach to problems dealing with mind and brain will have a realistic underlying pattern of thought to which to attach itself.

Speaking generally, these machines will be a challenge to the scientists of the future and will make great demands upon their ingenuity to formulate the problems of nature in mathematical terms. But there is another and less obvious possibility for the future. In much the same way that Babbage's machine of a hundred years ago had a salutary effect on branches of mechanical engineering so may the computing machines of the present have an important vitalising effect on the design of automatic machinery. The idea of automatic machinery is not new—the Jacquard loom, the dialling telephone, the petrol engine, the thermostat, etc., are examples. But what is new is the possibility of multi-purpose automatic control of industrial processes and other facilities. A factory operating entirely without human aid, but on the basis of programmed instructions, is not impossible. A multi-purpose factory of this kind, turning out china-dolls, shall we say, on the basis of one set of instructions, and offensive armament, on the basis of another set, is no doubt far-fetched. But there are certainly groups of related manufactured commodities which could probably be made under such conditions. A factory of this kind would be a triumph of engineering and ingenuity, but whether it is worth making will depend on circumstances.

However, apart from these fantastic speculations, merging as they do with those of Cybernetics, the real prospect remains that the development of automatic digital computing machines should produce interesting developments in the field of automatic machinery. Printing, sorting, reference-finding, typing, temperature control, weather forecasting and other spheres, all present problems which may in future be solved by the use of automatic machinery.

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Mathematical Tables Past and Future

by

Dr. A. Fletcher

In talking about mathematical tables, I should like first of all to consider what kind of need for mathematical tables exists. It hardly requires stressing that some sort of need exists; even the Babylonians in ancient times had quite extensive tables on clay tablets! Probably most of my audience possess mathematical tables of some kind, for good and sufficient reasons. Mathematicians themselves are by no means always interested in the numerical values of the functions they work with, but users of mathematics very often have their

own numerical problems and are concerned with mathematics largely as an instrument of calculation. The navigator must have his nautical tables, the statistician his statistical tables, the accountant his interest tables ; mathematical tables are always liable to be required by physical scientists and engineers.

The nature of the need varies greatly from subject to subject. Those performing precise computations in positional and gravitational astronomy, or in geodesy, say producing the *Nautical Almanac* or the *Air Almanac* or adjusting a trigonometrical survey in Africa, have a definite need for error-free trigonometrical tables giving, say, six to eight figures. Many modern applications require tables of more advanced functions. Elliptic functions are of interest, to give only one example out of many, in connection with the inductance of coils in electrical engineering. Bessel functions occur in a large variety of electrical and other engineering contexts. Anyone concerned with analysing the variation of a quantity over the Earth's surface (atmospheric temperature and pressure, gravity, tides, magnetism, and so on) is liable to require tables of spherical harmonics and Legendre functions. The number of kinds of function required in applications is growing all the time in apparently endless fashion.

For large programmes of systematic calculation the numerical values may be put on to punched cards, the uses of which Mr. Young is to talk to you about. In many cases the cards are punched from a table which has already been printed and thoroughly checked. Small and casual calculations are usually performed with the help of printed tables. This talk relates primarily to printed (or duplicated) mathematical tables.

Let us consider briefly how many figures are normally required in mathematical tables. It is safe to say that the investigator working on experimental or observational material usually needs tables giving from three to eight figures. It is not often that more than eight are really needed, as physical quantities can rarely be measured with greater accuracy. Sometimes, however, there is a loss of accuracy in calculation ; for instance, the difference of two nearly equal quantities is determined to fewer significant figures than the quantities themselves. In such cases the user will need tables giving more figures than usual. Moreover, the table-maker who wishes to be able to guarantee the accuracy of the last figure needs to have working values to two or three more figures than he proposes to print. Consequently it is convenient, and time-saving in the long run, to have fundamental tables giving twelve or fifteen figures in the case of basic functions, such as logarithmic, trigonometric and hyperbolic functions, and so on. Moreover, it is a good thing to make some systematic provision for the calculation of isolated values of basic functions to even more decimals on special occasions. In some cases it may seem that computation has advanced far ahead of need. Thus, the important constants π and e are now both known to two or three thousand figures ! Yet even these results are not without interest, since they lend themselves to statistical discussion of whether the ten digits 0, 1, 2, . . . 9 occur in a random fashion. With π this is more or less so, but in the case of e the distribution is suspected of being non-random. It is not that the various digits occur in too unequal numbers, but that they occur in too nearly equal numbers, to be compatible with randomness. If this is of no interest to those concerned with the evaluation of experimental and observational data, it must surely be of some interest to mathematicians.

Let us now consider to what extent, and in what manner, the need for mathematical tables has so far been met. This is manifestly not the occasion for a complete catalogue, but I should like to indicate briefly the present position in relation to a few of the more standard kinds of tables.

To start with something very simple, I need not say much about multiplication tables. Multiplication was robbed of much of its difficulty by the invention of logarithms over 300 years ago, and the multiplication of numbers having up to, say, ten digits has become very easy through the widespread use of desk calculating machines during the present century. I will, however, say that there are available accurate tables giving exact products of any two three-figure numbers,

and also of any two-figure by any four-figure number. These tables tend, however, to be about as big as a fair-sized office ledger. Tables of handier size, giving products of any two-figure by any three-figure number, can be very useful; I regularly take one from its shelf when my electricity and gas bills arrive. It is remarkable how pen-and-paper long division by, say, a three-figure divisor is facilitated and quickened by use of such tables; this kind of long division becomes really easy. I may add that tables of this sort are mostly foreign, because such tables are of much more use as ready-reckoners abroad than they are in this country, with its non-decimal money, weights and measures.

Let us now consider tables of natural trigonometric functions—sines, cosines, tangents, etc. It might be thought that all needs would have been satisfied long ago, but this is true only for the sexagesimal division (degrees, minutes and seconds). In this system of units a wonderful feat of computation was performed by Andoyer in Paris in the years 1910–14. He produced accurate tables of all six trigonometrical functions to 15 decimal places at interval 10″ throughout the quadrant, and so provided a very secure source for editors compiling working tables to fewer decimals. Rather similar tables were made over three centuries ago, by Rheticus and Pitiscus; their trigonometrical canons were gigantic and admirable works for their time, but they were not accurate, as Andoyer's are. I have called Andoyer's feat of computation wonderful because he computed his tables in a few years, without the help of any assistant or any calculating machine; his only help was one of the three-by-three figure multiplication tables which I mentioned earlier.

But modern practice is freeing itself from the use of the sexagesimal division as much as it can. It is evidently more convenient in a general way to choose some angular unit and then divide it decimally, but there are difficulties. Sexagesimally graduated instruments are still widely used, and there is a vast accumulation of observations in sexagesimal measure. Navigators use nautical miles, and a nautical mile subtends one minute of arc at the centre of the Earth. Units of angle are intimately related, through such things as longitude and hour angle, to units of time, and our traditional 24 hours are subdivided sexagesimally; moreover, the second of time so obtained is the basic unit of time in the c.g.s. system. Still, there are many contexts in which one can use an angular unit divided decimally, and so make special sexagesimal computing machines or arrangements unnecessary.

Even in 1633 Briggs and Gellibrand divided the ordinary degree decimally, and published tables to 10–15 decimals at interval 0°·01. A recomputed version of the sines and cosines has been published by the National Bureau of Standards in Washington, but the other functions still lack first-class fundamental tables. Good working tables are available up to at least seven figures.

In current use, the principal alternative to the sexagesimal division is the centesimal division, which dates from the time of the French Revolution. The right angle is divided, not into 90 degrees, but into 100 grades, which are subdivided decimally. This system is much used on the Continent for surveying; for example, it was adopted for all surveying (except geodetic surveying) in the whole of Germany by ministerial decree in 1937, and is still in use. Good working tables are available up to about eight figures, but fundamental tables are not as full as one could wish.

What appears to me to be the ultimate division for many purposes in astronomy and other subjects is still at a rudimentary stage of development, in spite of having been proposed in the time of Briggs. I refer to the division of the whole circumference (not the quadrant) decimally. Its advantage is that, in finding trigonometrical ratios of angles, such as planetary and satellite longitudes, which can go through many revolutions, we do not subtract multiples of 360° or 400^g, but merely drop the integral part. I think engineers also would be glad to measure angles in revolutions. Tables by Bower, formerly of the Lick Observatory, are now available on punched cards and in machine print. Earlier tables were mostly small.

For non-trigonometric purposes the fundamental unit of angle is, of course,

the radian. This is always subdivided decimally, so that there are no competing systems of subdivision. Yet it is only for sines and cosines that both working tables and source tables are something like adequate.

It will be seen, then, that even in tabulating trigonometrical functions we are still far short of finality.

On the tabulation of common logarithms (logarithms to base 10), I am able to report rather more favourably, but this is the first British Association meeting at which one can say so much. Towards the end of 1952 there was published the last part of Dr. A. J. Thompson's monumental *Logarithmetica Britannica*, begun in 1922. This work gives highly accurate 20-decimal logarithms of all integers up to 100,000. Many-figure logarithms of integers considerably greater than this limit have several times been calculated, and I think it would be advantageous to publish some of them, but apart from this we do at last appear to have reached an end of desirable tabulation of common logarithms of integers.

Logarithms of trigonometrical functions, like natural values of trigonometrical functions, have suffered in tabulation from the multiplicity of angular units. But the use of logarithms in computation has declined, and I will not dwell on this topic.

It is, of course, only the use of common logarithms which has declined. The natural logarithm, or logarithm to base e, is a fundamental mathematical function. Source tables are adequate, largely through the efforts of the National Bureau of Standards, but one could wish for better working tables.

We are now so used to working with exponential and hyperbolic functions that we may be surprised to realise how recent, historically speaking, has been the development of tables of these functions. There were no tolerable fundamental tables of e^x and e^{-x} until the 1880's, while such tables of sinh x and cosh x were not made until the period 1926–40. There were a few working tables, often not very accessible and not very accurate; even small working tables of sinh and cosh were almost unknown in this country until the publication of Dale's tables in 1903. Even now there are no fundamental tables, and very few working tables, of sech and cosech. There does however exist, in Comrie's six-figure tables, a collection of tables of direct and inverse circular and hyperbolic functions of the utmost utility.

It is, of course, possible to limit mathematical tables very much if one confines oneself only to very essential tables. The outlook a century ago seems to have been something like this. If you want a value of e^x, you can multiply x by the modulus M of common logarithms (using either logarithms or a table of multiples of the modulus); then a table of antilogarithms, or a table of logarithms used inversely, will give $10^{Mx} = e^x$. If you want e^{-x}, you just take the reciprocal (probably by logarithms). If you want cosh x, you just add e^x and e^{-x} and divide by 2. If you want sech x, you just take the reciprocal of cosh x. And so on. Evidently one can do all these things, but I think it will be obvious to everyone that this is a very uneconomic and unstreamlined process. Those who compute a good deal have a genuine need for quite a lot of tables which might be dispensed with, but are much better not dispensed with. We must be glad that tabulation of exponential and hyperbolic functions, if by no means as complete as one could wish, is at least in much better shape than it was eighty years ago.

I will not go into much detail respecting tables of advanced functions, but I think a similar remark would apply to them. At least the more standard kinds of advanced functions are now fairly fully tabulated. Excellent tables of the Jacobian elliptic functions were published in 1947 by the Spenceleys, of Oxford, Ohio; these tables are much fuller than any of their kind published previously. Tables of the Legendre functions were published principally by Tallqvist in Finland in the years 1904–38.

Above all, the tabulation of Bessel functions, important in so many applications, has been much developed. In this the British Association has played a great part. Its committee on Mathematical Tables, from its inception in 1871 until its replacement by a Royal Society Mathematical Tables committee in 1948,

indeed contributed greatly (as the Royal Society committee continues to do) to many fields of mathematical tabulation ; but it gave special attention to the tabulation of Bessel functions, and (apart from tables published in the annual reports) it published, in 1937 and 1952, two splendid volumes of tables of Bessel functions. In America also there has been great activity in the tabulation of Bessel functions. The I.B.M. Automatic Sequence Controlled Calculator at Harvard was put on to the automatic tabulation of Bessel functions. It calculates the values and prints the results, and has enabled volumes of values of $\mathcal{J}_n(x)$ to be published almost faster than computing establishments can purchase them ! The latest volume deals with integral orders n from 79 to 135.

The whole field of Bessel function tabulation is evidently a large one. Consider, for instance, $\mathcal{J}_n(x)$, which is only one of several kinds of Bessel function. The value of the order n need not be integral ; halves, thirds and quarters of integers, at least, are needed in applications. The value of x is quite unlimited. In fact, x may be complex ; tables for complex argument have been published by the National Bureau of Standards. It is not possible to draw a hard-and-fast line between essential and luxury tabulation ; one can, however, say that a substantial part of the essential tabulation of Bessel functions appears now to have been done.

I will not dwell any longer on tables of particular functions. I would, however, like to say a few words about the manner in which tables were computed or drawn up until quite recent times. Those who are interested in the bibliography of mathematical tables will be familiar with the great difficulty which has arisen in the last fifteen years or so in describing at all concisely the authorship of a considerable number of tables, issued, often in duplicated rather than printed form, by bodies which are often government agencies of one sort or another and which frequently have complicated and changeable titles. This difficulty, however, scarcely existed at all before the Second World War. The immense majority of tables were printed under the names of one or two individual authors, and were conveniently referred to by those names.

But we must not be deceived into thinking that tables, when not merely put together by extraction from other tables, were invariably computed by single individuals, or possibly by two co-operating authors. In fact, a number of the best known tables were computed by team work. Sometimes this was of a straightforward kind. A mathematician would employ computers ; thus for twelve years Rheticus constantly had some computers at work. There was also, under the French Revolution, a foretaste of mass-production methods in the highly-organised team set up under Prony which computed, unfortunately not by the best methods, the logarithmic and trigonometrical tables usually known as the *Tables du Cadastre*. Sometimes, however, the arrangement was of a less direct kind ; mathematical instructors decided that it would be good training if their classes helped them to carry out quite large pieces of work. Thus Vega, the editor of several well-known and much-used collections of tables, was an officer and mathematical teacher in the Austrian artillery, and it is clear from his prefaces that he organised numbers of his pupils, officers and men, both at headquarters in Vienna and on active service in the Napoleonic Wars, to help in the extensive checking of numerical values. There is even the case of the gentleman who in mid-Victorian days was employed to give mathematical instruction to two young ladies, and with the help of their computations produced quite a good book of seven-figure logarithms !

It is evidently a great advance that large pieces of work involving thousands of repetitions of definite schedules of computation can now so often be performed by automatic machines. Even to an enthusiastic computer, almost unending repetition can be a drudgery. We must be glad that the engineers have come to the rescue and are increasingly setting mathematical labour free for other purposes.

I would now like to say a few words about the indexing of mathematical tables. Glaisher says that the purposes for which the British Association Mathematical Tables Committee was appointed in 1871 were twofold, viz. (1) to form as

complete a catalogue as possible of existing mathematical tables, and (2) to reprint or calculate tables which were necessary for the progress of the mathematical sciences. The first objective, that of cataloguing existing tables, was in large measure attained through the publication of Glaisher's classic 175-page report to the meeting of the British Association in Bradford in 1873, just eighty years ago, supplemented by Cayley's report, two years later, on tables in the theory of numbers. But this work was not continued and kept up to date by the Committee, which came to devote its efforts almost entirely to the computation of new tables. Thus over sixty years elapsed before the publication of similar extended and systematic indexes to tables, namely D. H. Lehmer's *Guide to Tables in the Theory of Numbers* in 1941 and *An Index of Mathematical Tables* by members of the Department of Applied Mathematics in this university in 1946. In the meantime there had certainly been encyclopedia articles by Mehmke and by Glaisher, a detailed account of tables of logarithms of numbers by Henderson, and bibliographical lists by Davis, all of which we found very useful and valuable, but evidently of somewhat more limited scope than the Glaisher-Cayley reports.

Yet before any tables are calculated or reprinted, Glaisher remarks that it is absolutely essential to be certain that they are not already in existence or easily accessible, and we may at least agree that this is highly desirable. The vast proliferation of mathematical tables since the 1870's has made it harder and harder to attain this certainty on the rather informal basis of the well-stored memories of a few scientists specially interested in the field of mathematical tables. You will appreciate the difficulty if I point out that our by no means complete card-index of mathematical tables contains about 5,000 cards, of which about a thousand relate to items published in the last ten years.

This card-index is arranged in alphabetical order of *authors*, but requests for information usually reach us in the form, 'Do you know of any table of such and such a mathematical *function*?' The first edition of our book consisted essentially of an index according to function of the most important tables up to, say, 1944. Only about two-thirds of the more recent tables have so far been indexed according to function, as far as work in Liverpool is concerned. Accordingly, it sometimes happens that to the question 'Do you know of any tables of this function?' we can answer 'Yes' with certainty, but at the present stage of the work it rarely happens that we can answer 'No' with certainty, unless we do rather a lot of time-consuming special searching. We are, however, convinced of the importance of carrying on the work of indexing according to function. When the second edition of our book appears, its Part I will, as in the first edition, constitute an index, arranged according to type of mathematical function, of all the tables which have come to our notice and appear suitable for inclusion in a work which must necessarily be somewhat selective unless it is to grow intolerably. Perhaps I may also be allowed to say that the second edition will also contain an entirely new Part III, giving lists of errors in some five hundred of the more important tables, or references to places where such lists may be found. It was originally planned that this part should be contributed by the late Dr. Comrie, who did make a beginning of arranging and writing up his unique store of information relating to errors in tables. Our principal aim in continuing this editing has been to make the fruits of his lifelong interest in the detection of errors in tables publicly available, and so save important material from neglect. I am glad to say that this Part III is now almost completed.

Finally, I suppose I ought to consider whether the need for mathematical tables of the ordinary kind is likely to be permanent. Is pen-and-paper calculation, with or without the use of desk calculating machines, likely to become completely outmoded as more and more work is handed over to automatic computing machines? I imagine that most people will agree that this is not very likely. Pieces of work have to be rather large and systematic before they are worth doing on automatic computers. It seems to me that in the kind of activities which I mentioned at the beginning of this talk, there will always be plenty of occasions

on which people will need to perform casual calculations or systematic computations of limited extent. If one is given a problem in which numerical answers are required, one often has to do quite a lot of exploratory work before one hits on a reasonably practical method of obtaining the required answers. Moreover, the answers are not always wanted for a large number of cases corresponding to different numerical data. Sometimes they are wanted for only one or two cases, and it is a matter of performing one or two long computations of a varied character rather than of repeating a definite sequence of steps a large number of times. I imagine that for a long time yet there will be plenty of people in research establishments and elsewhere turning the handle, or pressing the button, and looking values up in tables. No doubt the range of mathematical functions which they require to have available in numerical form, like the range of mathematics which they require generally, will expand and alter and develop. Rather than the demise of ordinary mathematical tables, I anticipate their improvement and extension.

The Use of Punched Cards in Science and Administration

by

A. Young

The ever increasing size and scope of the archives containing the information upon which our modern society depends for its functioning give rise to problems of administration and documentation which, if unsolved, would delay society's further development.

In the eighteenth century, when the complete documentation of knowledge was the aim of the great French encyclopedists, their task seemed to have sufficient prospects of being successfully completed to justify the attempt. To-day their successors are steadily losing ground. It is, for example, reported that the eighth edition of the *Gmelin Handbuch* which covers the field of inorganic chemistry may well be the last. It will have taken over forty years to prepare this edition when it is finally completed. The editor has written that the era of the classical handbook is approaching its end. The reason is not far to seek. In the two hundred years preceding 1926, the date of publication of the volume on Zinc in the eighth edition of the *Gmelin Handbuch*, 7,281 publications concerning this metal had been recorded. In the following twenty-three years, 19,431 publications have been recorded. This volume of scientific publication has led to the assertion by the editor of the Handbuch that, ' It has now become evident that what can be accomplished by printing is now approaching its limit, in fact, may have already reached it even to-day ' (1) (p. 429) Anyone who has had the experience of searching the literature of an ill-documented branch of science must have considerable sympathy with this view. The basic problem, however, remains that which prompted the encyclopedists—the presentation in readily accessible form of all useful knowledge. ' The difficulty,' according to Vannevar Bush, ' seems to me, not so much that we publish unduly in view of the extent and variety of present day interests, but rather that publication has been extended far beyond our present ability to make real use of the record ' (2).

The problem is not unique to science for it is endemic in society. To take but one of a host of examples from industry and commerce, from 1910 to 1939 the total volume of industrial assurance business in Britain quadrupled. To-day one company, accounting for some 15 per cent. of the total new business transacted, issues about a million new policies per year. Each policy is an individual financial contract between the issuing company and the policy holder, and involves the weekly or monthly payment of a premium. In the field of British industrial assurance alone, therefore, something of the order of 200 million financial accounts have to be itemised every month. The regular perusal of this vast number of records necessitates the maintenance in a readily accessible, and extremely flexible, form of all the data relevant to each aspect of the administration of the business.

The solution of the administrative problem in the insurance field has, in the main, but not entirely, been due to the

adoption of mechanised accounting based on punched-card techniques.

When Hollerith realised that the mere volume of material to be collected by the decennial census of the U.S.A. in 1890 would defeat the digestive powers of conventional methods of recording and analysing data, he set about devising a workable method of recording information on cards by means of punched holes which could be used to actuate the mechanism of machines capable of performing certain simple operations at speed. He was not the originator of the idea for it was clearly envisaged by Babbage many years before, but where Babbage failed, Hollerith succeeded in developing the equipment and technique to the point at which they were suitable for general use.

Conceived originally for use in scientific calculations of simple nature but large extent, Hollerith's machines were intensively developed because of the application to commerce of their accounting and book-keeping facilities in indexing, extracting and collating information. It is as ' accounting machines ' that they are now known. Their characteristic virtues are the speed at which simple repetitive operations can be performed, reliability, and flexibility leading to ease of changing programmes of work. Major industrial and commercial applications of these machines to stock analysis, maintenance of sales records, production of salary rolls, invoicing, etc., clearly make full use of these virtues. In fact, the problem of machine utilisation is seldom ' Can the machine do it ? ' but ' Are there enough operations of the particular type required to ensure the economic use of the expensive machinery ? ' This exposes the major limitation of the equipment. It is seldom economical when used on tasks which do not involve really large quantities of data and also much repetitive handling.

In the commercial world, however, there are many businesses whose records are large but not quite extensive enough to justify the use of punched-card machinery. Loose leaf files and simple card indexes have largely replaced the old fashioned bound ledgers but these expedients fail as soon as multiple classification of records is required owing largely to the fact that sorting and rearranging card indexes is a painfully slow procedure. The concept of the original punched card applied to the simple card index has produced the edge-punched card index system which combines facility for rapid sorting with economy, whatever the size and complexity of the task to which it is applied. These cards are sorted manually at great speed with the aid only of a simple knitting needle.

The chief scientific application of such cards is identical in principle with their use in industry and commerce. Casey and Perry record many applications including the geochemical classification of coal specimens, anaesthesia records, textile factory production control and systematic indexing of organic chemical compounds. These cards find perhaps their greatest potential use in the field of bibliography where they are, in fact, already in widespread use. A card carrying an abstract of a scientific paper can be punched to give such details as author, source reference, date, main and numerous minor subject classifications, and so on. An index containing such cards will quickly answer such queries as ' Has anything been published relating to the application of matrix methods of solving integral equations arising in aerodynamic supersonic flow problems ? '

Card systems of this type are available made from sensitised material suitable for photo-copying processes or with frames into which micro-films can be inserted. The latter suggests the filing of whole libraries in punched card indexes. It seems that the role of the encyclopedist has been taken over by the abstractor and card indexer.

Mechanically sorted punched card systems, of course, can be, and are, used for this type of work, but are not so flexible in many ways. The possibility of using mechanically sorted punched cards to produce printed bibliographical records should, however, be mentioned.

Coding cards for scientific uses is a fascinating art, as yet in its infancy. What is an efficient code in one application may be grossly inefficient elsewhere. For example, a bibliographer confining his attention solely to geophysical works, would find it necessary to include certain branches of archaeology as sub-classification head-

ings when dealing with geodynamical papers. The system of classification in this instance would clearly confound the users of a general library catalogue ! It might also be pertinent to remark that coding requires the resolution of a dilemma, since card economy, simplicity of coding, card preparation and sorting, are to some extent mutually exclusive. If, for example, classification should prove adequate using say five letters from the author's name, it would be possible, assuming the English alphabet, to allot five twenty-six hole fields for the purpose. Card preparation and sorting would be simple at the expense of card economy. However, of the large number of possible five-letter combinations, a large proportion would never in fact occur ; a binary code using ten holes would give 2,047 five-letter combinations which might be adequate in practice and so provide maximum card economy with easy sorting but would require a coding index to which every user would need to refer.

In the field of scientific computation, applications of punched card systems are widespread. The impact of electronic engineering has led to the introduction of machines capable of performing much more sophisticated operations than the original range of equipment and conditions are rapidly being changed by these developments. But such machines are as yet not widely available, and at least for small or medium scale computing establishments, punched card computing is virtually confined to the use of the standard equipment in common use commercially. The basic equipment necessary includes the sorter, reproducer, tabulator and collator. The tabulator, which is essentially an adding machine, is used for multiplication by the adopting of one of several ways, all of which typify the dictum that the use of the equipment is only justified for large-scale repetitive work. Iterative processes do not often prove economical on this equipment.

The machines have found wide application in statistical work where they are eminently useful for the evaluation of the lengthy sums of products which frequently occur. They are used for this latter purpose in crystallographic research involving Fourier synthesis and also in the general field of analysis of time series and Fourier Analysis.

Table makers have frequent recourse to the machines for the preparation of difference tables and, more important, for the making of tables by sub-tabulation processes. As an indication of the speed of operation, an 8 decimal place table containing 1,000 values of a certain function was produced by sub-tabulating a table of 100 pivotal values to tenths in one afternoon's work on a tabulator. This included the time taken to travel to the installation and also to set up the machine.

There is a growing number of mathematical tables recorded on punched cards. As an example, in many problems functions are well represented by sums of exponential terms $\sum_i A_i e^{k_i x}$. Since a change in the parameter k_i is equivalent to a change in the interval of the argument x, it is only necessary to prepare a set of cards of e^x at a suitable interval in x as argument. To extract the tabular values required, $k_i x$ is punched on to a set of cards and this set, together with the table set, are passed through a collator which sorts out the cards in the table corresponding to the values required. Obviously the economy of this process depends on large scale need, but this does occur sufficiently often to justify the preparation of such sets of tables.

Applications of the more sophisticated but less accessible punched card electronic equipment include the following, taken at random from published papers :

' A punched card application of the Monte Carlo method' ;

' Automatic computation of the roots of complex polynomial equations ' ;

' The calculation of complex hypergeometric functions ' ;

' Numerical calculations of integrals of the type $\int_\alpha^\beta f(x)\, g(x)\, dx$.'

This equipment is, of course, capable of handling routines which do not involve large masses of data.

Just as punched card equipment manufacturers are utilising the development of the electronic engineer, so the engineers responsible for some of the automatic sequence controlled electronic calculators

are using punched card equipment to overcome difficulties with their machines. Several are using punched cards to feed data into their calculators and also use punched card printing equipment to record results.

It is unfortunately the case that, although there is adequate provision for the dissemination of knowledge about the use of punched card equipment deliberately designed for scientific computing, more is known about computing with the machines in general commercial use than has been published. Much of the 'know-how,' particularly in regard to time-saving devices, is communicated privately between initiates when they meet. This is partly because of the difficulty of finding journal editors willing to publish the technical details relevant to the consolidation of punched card techniques at a time when automatic computing development is so spectacularly influenced by the large electronic machines. L. J. Comrie (3) contended that 'the discovery of the usefulness of an available commercial machine at least ranks with the design of special machines, and it is emphatically urged that the possibilities of existing mass-produced machines should be exhaustively explored before design is even contemplated.' One need not agree with the entire implications of this remark to realise its value.

Since punched card installations are often employed commercially to deal with very large seasonal floods of work, the users are, in our experience in Liverpool, quite often willing to allow one to make use of the machines during the 'off season' at little or no expense. The value of this to small or medium scale computing establishments is obvious, and would make the further exploration of punched card techniques well worth while, even if no other reasons existed for doing so. It presents a stimulating challenge of improvisation to the computer because, in Britain at any rate, he will often have to adjust his methods to suit machines designed for use with sterling currency.

Examination of machine design shows that, in theory, small accounting machines such as the National can be used to do almost everything that a tabulator can do. In Liverpool we have shown by experiment that the adoption of edge-punched cards makes it practicable to use tabulator multiplication techniques on the National accounting machine and in some circumstances it is the most economical method for small computing establishments to adopt. So far as we know, this is the first application of edge-punched cards to actual computing techniques.

In conclusion it might be useful to indicate a use of edge-punched cards as an effective ancillary aid to computing. In a recent investigation seventy-two consecutive monthly values of each of the moments and products of inertia of the Earth's atmosphere were calculated from recorded pressure data which were unfortunately presented as functions of place and time, with place the main argument, so that, in order to find if data for a particular station were complete, seventy-two different pages of six different volumes had to be consulted. In practice all the data were collated by being extracted on to ruled paper with time as the main argument. Stations with incomplete records were then rejected, or where necessary absent records were interpolated. Where changes had occurred at stations during the six-year period, the data had to be adjusted so that records were consistently based throughout the period. In other words, the data required severe editing before computing began. This work took three months to complete. For each of 350 stations finally used, factors were calculated relevant to the required moment or product and finally pressure data and factors were punched on to cards, there being one card per station per year. Over 155,000 individual products (pressure $\times$ factor) were required to be summed in over 500 different runs. This was done in a few hours on a tabulator. Certain points are worth noting. This amount of product summation could be done in a matter of minutes on modern automatic sequence controlled computers at the rates of multiplication claimed, but in fact the time saving would have been a negligible part of the total time taken for the project, since the data had to be prepared, cards (or tape) punched and results printed. For this type of work punched card techniques are more economical than those of giant electronic machines.

The extraction of the data from the original source directly on to edge-punched cards, however, would have saved hours of editing time because of the ease with which individual station records could have been inspected and adjusted. This saving would, by itself, have justified the use of edge-punched cards prior to the preparation of cards for use with the tabulator, but had the particular investigation been for only a year, say, the edge-punched cards would have been ready for immediate use in conjunction with a National accounting machine. The time lost compared with the faster tabulator process would have been largely offset by the time saved in card preparation and verification, and by the financial saving due to the use of much cheaper equipment.

Bibliography

No descriptions of equipment are given in this paper but readers will find good descriptions of punched card machines in references (1) and (4). Numerous applications of punched card machines will be found in (5), (6), (7) and (8). The application of edge-punched cards to computing on the National Accounting machine is described in (9). Bibliographies of punched card tables will be found in (10) and (11).

(1) Casey, R. S., and Perry, J. W., *Punched Cards. Their applications to Science and Industry.* Reinhold Publishing Corp., N. York (1951).
This is an extensive survey of the use of punched cards with emphasis on the applications of edge-punched cards.
(2) Bush, V., *Atlantic Monthly*, **176**, 101–8 (1945).
(3) Comrie, L. J., *J. Roy. Stat. Soc. Supp.*, **3**, pp. 87–114 (1936).
(4) Hartley, H. O., *J. Roy. Stat. Soc. Supp.*, **8**, pp. 154–183 (1946).
(5) International Business Machine Corporation, *Proc. Scientific Computation Forum* (1948).
(6) International Business Machine Corporation, *Proc. Computation Seminar* (1949).
(7) International Business Machine Corporation, *Proc. Industrial Computation Seminar* (1950).
(8) International Business Machine Corporation, *Proc. Computation Seminar* (1951).
(9) Young, A., *Quart. J. Mech. App. Math.* (in print).
(10) Blanch, G., and Yowell, E. C., *M.T.A.C.*, **5**, pp. 185–212 (1951).
(11) Blanch, G., and Yowell, E. C., *M.T.A.C.*, **7**, pp. 1–6 (1953).

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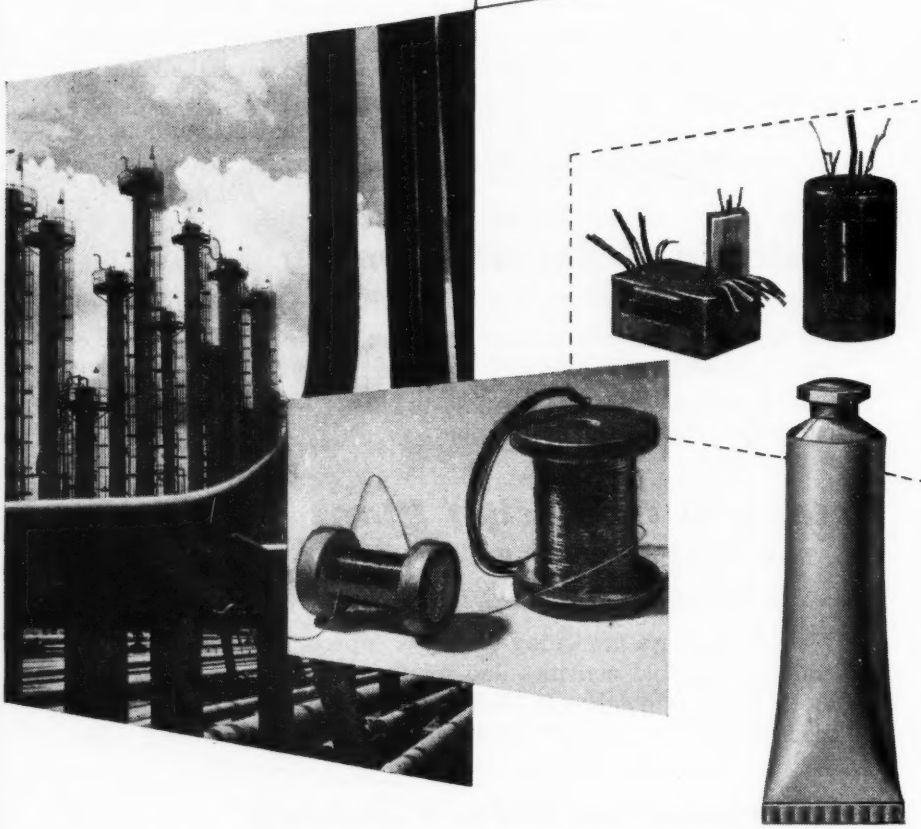

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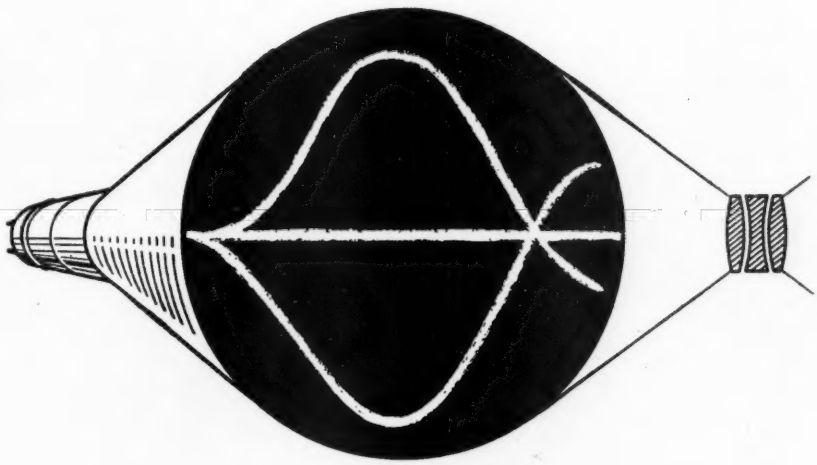

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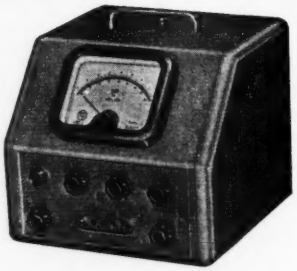

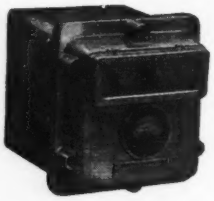

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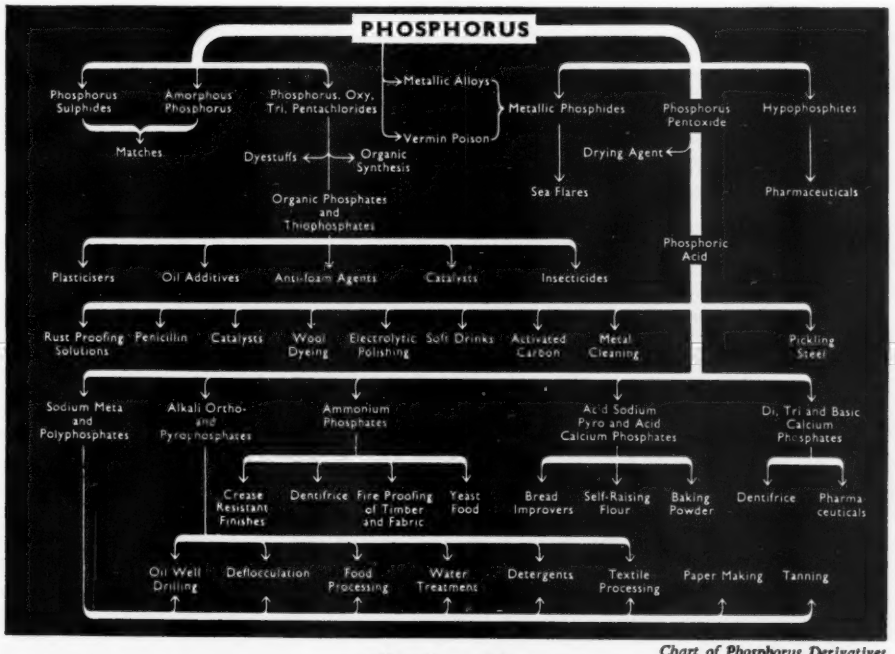

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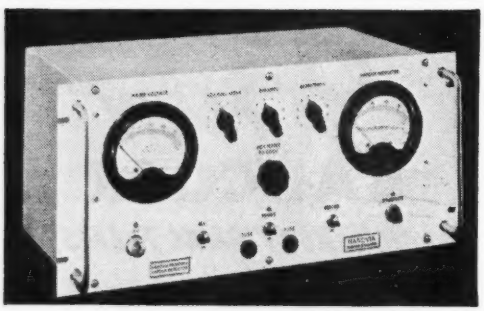

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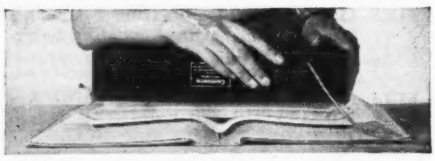

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